PART I	PRESSURE SHIPS
Chapter I	General Description
Chapter II	General Operating Principles Loading Discharging Refrigerating the Cargo Gas-freeing
Chapter III	Cargo Handling Equipment Cargo Pumps Cargo Compressors Condensers Heat Exchangers Cargo Heater Vaporiser
Chapter IV	Conduct of Cargo Operations Semi-refrigerated Cargoes Loading Discharging Refrigerating the Cargo Gas-freeing Fully-refrigerated Cargoes at Atmospheric Pressure Loading Discharging Two-stage Refrigeration Precautions to be taken When Starting a Compressor Points to Watch Whilst a Compressor's Running
PART II	FULLY-REFRIGERATED SHIPS
Chapter V	General Description
Chapter VI	General Operating Principles Loading Refrigerating the Cargo on Passage Two-stage Reliquifaction Cascade Reliquifaction Discharging Gas-freeing To Gas-up the Tanks After They Have Been Gas-freed To Cool Down the Tanks Prior to Loading Summary of Gas-freeing and Gassing-up
Chapter VII	Cargo Handling Equipment Two-stage Refrigeration Two-stage Compressors Seawater-Cooled Condensers The Inter-stage Cooler The Heat Exchanger Cascade System of Refrigeration R.22 Compressors R.22 Condensers R.22 Receivers The Cargo Compressors

	The Cargo Condensers
	Methanol Injection System
	Vaporisers
	Air Dryer
	Cargo Heaters
	Submerged Cargo Pumps
	Emergency Cargo Pumps
	Deck Storage Tanks
Chapter VIII	Cargo Operating Procedure
	Loading
	To Refrigerate the Cargo on Passage
	Two-stage Reliquifaction
	Points to Watch Whilst the Plant is Running
	Cascade System of Reliquifaction
	Starting the Compressors
	Points to Watch Whilst the Plant is Running
	To Shut Down the System
	Other Points to Watch
	Discharging
	To Gas-free the Vessel
	Puddle Heating
	To Estimate the Time it Will Take to Puddle Heat
	Tank Warming
	Inerting the Cargo Tanks
	Flushing Through with Air
	Preparing the Tanks to Receive Cargo After They Have Been Gas-freed
	Drying the Air in the Cargo Tanks
	To Operate the Air Dryer
	To Inert the Tanks Prior to Gassing-up
	To Gas-up the Cargo Tanks (at Sea)
	To Gas-up the Tanks Alongside
	Cooling Down the Cargo Tanks
	Procedure When Changing Grades and Types of Cargo
PART III	GENERAL
Chapter IX	Cargo Calculations
	To Calculate the Quantity of Liquid on Board (Metric)
	To Calculate the Weight of Vapour on Board (Imperial and Metric)
	Assessing the Volume of Vapour
	To Calculate the Quantity of Liquid on Board (Imperial)
	To Calculate the Correct Volume of Liquid to Load When Loading a Full Cargo
	Expansion Relief Valves on Liquid Lines
	To Calculate the Correct Volume of Liquid to Load When Loading a Part Cargo
	To Calculate the S.V.P. of a Mixture of Products at a Given Temperature
	To Calculate the Individual Proportions of Vapour in the Vapour Mixture Above a Liquid Mixture
	Molecular Weights
	Aid to Memorising the Formulae
	Comparison of Metric and Imperial Systems
	Table of Properties

Chapter X Safety
Safe Navigation
Safe Practice
Gas Detection
Fire Detection
Fire-fighting
Precautions to be Taken when Entering Spaces which May Have a Deficiency of Oxygen

Chapter XI Recommendations
Safe Navigation
Harbour Control
Enforcement of Traffic Separation Systems
Emergency Isolation Valves for Safety Valves
Greater Consultation between Operators and Design Staff

PART I PRESSURISED SHIPS

CHAPTER I: GENERAL DESCRIPTION

Pressure ships can be divided into two types, namely fully-pressurised and semi-pressurised (semi-refrigerated). In practice, the designation of the two types of vessels has been contracted to Pressure Ships to describe fully pressurised L.P.G. tankers and semi-refrigerated to describe semi-pressurised ships. From this point on, this terminology will be used.

Pressure ships are the simplest vessels, and were the first to be built or converted, for the specific purpose of carrying L.P.G./Ammonia cargoes.

The cargo is carried in a number of cylindrical pressure vessels (cargo tanks) capable of withstanding the, maximum pressure likely to be met in service, (usually about 17 bars), the arrangement of the tanks being indicated in Fig. 1.

In order to act as a liquified gas carrier, the ship must be capable of loading, carrying and discharging, its cargoes, as well as having provision for gas-freeing for repairs or when changing types of cargo to be carried.

In liquified gas vessels no joints, glands, etc., are permitted below decks, in order to exclude the possibility of liquified gas or vapour leaking unnoticed below decks, so special arrangements have to be added to conform to this requirement. This means that the loading/discharging (liquid) lines have to penetrate the tank through the tank dome protruding through the deck.

The arrangement is shown in Fig. 3.

To drive the liquified gas from the bottom of the tank to the cargo pump suction, compressors are installed which, by taking vapour from a tank not being discharged (or fro -in shore through a vapour return line), pressurise the tanks being emptied; and drive the liquid to the pump suction. Therefore a pressure type liquified gas tanker is provided with:

(a) strong tanks (or pressure vessels) into which the cargo is loaded;

(b) a liquid line leading from the top of the cargo tank to the bottom through which the liquid gas cargo is loaded and discharged (these are also used for gas-freeing).

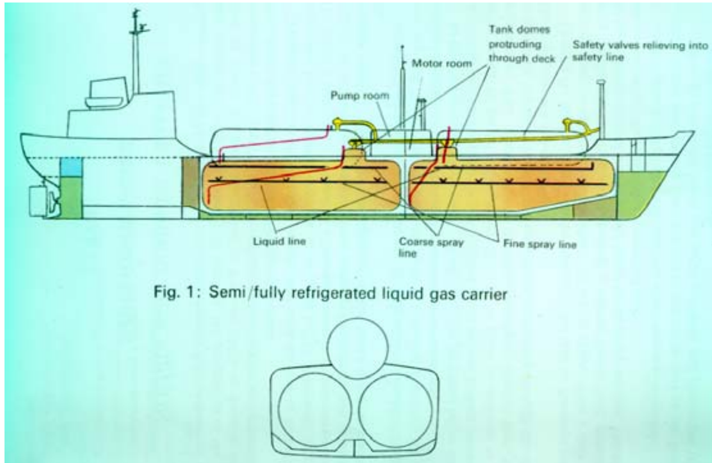


Fig. 1: Semi/fully refrigerated liquid gas carrier

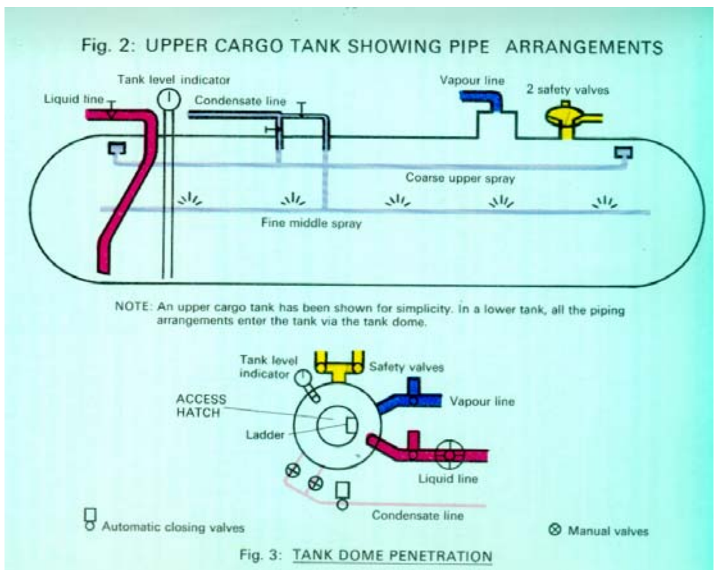


Fig. 2: UPPER CARGO TANK SHOWING PIPE ARRANGEMENTS

Fig. 3: TANK DOME PENETRATION

(c) compressors with which to pressurise the tanks being discharged in order to blow the cargo from the bottom of the tank to the cargo pump suction;

(d) a vapour line leading to the top of the cargo tanks which is used by the compressors to pressurise the tanks being discharged;

(e) cargo pumps to raise the discharge pressure and so pump the cargo ashore; and
a liquid manifold to which the shore loading/discharge lines are connected and linked to the ship's liquid line system, together with a vapour line connection which can be linked to the shore vapour line (if provided) and used either as a vapour source when discharging or pressure relief when loading.

The principal advantage of semi-refrigerated ships (semi-pressurised) is that the tanks containing the cargo need not be so strong because the pressure of the cargo is very much reduced by lowering its temperature. As a result, the following benefits are derived:

(a) more cargo can be carried in a tank of the same capacity (see Chapter IX - Cargo Calculations);

(b) a tank of the same capacity is lighter and cheaper to construct; and

(c) much larger and more economical tanks can be constructed.

Pressure ships usually range from very small capacity up to 2,000 cubic metres capacity. The capacity of semi-refrigerated ships usually range from between 1,000 to over 10,000 cubic metres. The cargo in the tanks is usually maintained at about O@ C. by a process of refrigeration, and the tanks them-selves are thermally insulated.

The loading and discharging procedures are generally similar in both types, the main operating difference being the addition in the semi-refrigerated ship of a, reliquifaction (refrigerating) plant to cool the cargo on passage, and also, under certain circumstances, to assist with loading.

In most vessels of both types, the cargo handling equipment is located in a deckhouse divided into two compartments by a gas-tight bulkhead. In the one half are located the electric motors to drive the compressors and pumps, which are separately housed in the other section, the driving shafts passing through the gas-tight bulkhead via gas-tight seals (see Fig. 4). The motor room is kept pressurised with air by powerful fans to exclude the possibility of gas entering the motor room, so avoiding a fire hazard.

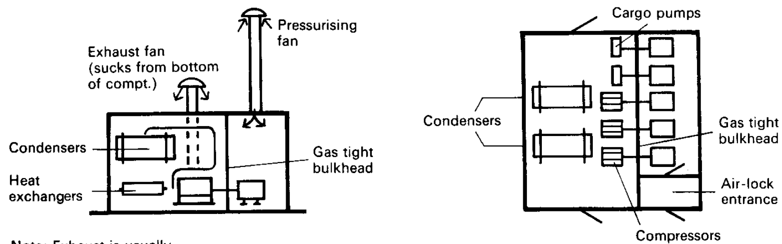
The tanks are usually discharged two at a time by blowing the liquid gas to the cargo Pump suction, where the discharge pressure is greatly increased by the cargo pump.

To blow the liquid gas to the pump, one or more compressors are started up, sucking vapour from one or more tanks not being discharged and sending it into the tanks being emptied. This is shown in Fig. 6. A simple vapour line arrangement to do this shown in Fig. 5, but in more advanced ships (particularly the semi-refrigerated ships) different arrangements are made to achieve the same result, often using different piping arrangements, but the principle of pressurising the tanks being discharged and blowing the product to the pump suction remains the same.

The latest development is to make semi-refrigerated ships capable of carrying fully-refrigerated cargoes at atmospheric pressure, which gives them greater versatility with regard to the cargoes that can be carried.

Hence, a simple general description of the all-purpose ship will cover individual types.

Fig. 4: L.P.G. and Motor Rooms showing gas-tight bulkheads and gas-tight seals



Note: Exhaust is usually below forced draught intake because L.P.G. vapours are heavier than air

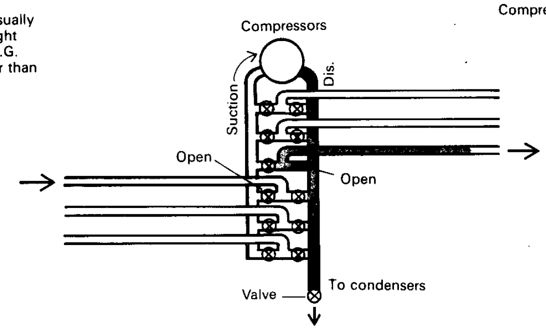
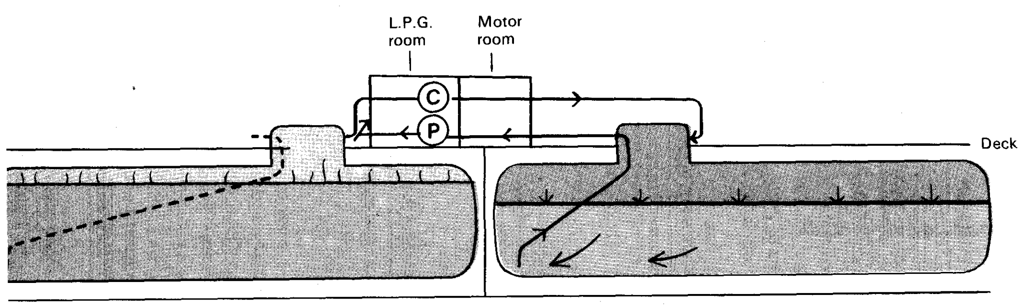


Fig. 5

Fig. 6: TANK DISCHARGING ARRANGEMENTS



TANK 'A' ACTING AS VAPOUR SOURCE

Vapour withdrawn by compressor (c) causes atmosphere in tank to become undersaturated. Withdrawn vapour is largely replaced by evaporation of liquid in tank, the evaporating process using up latent heat thereby cooling the liquid in the tank.

TANK 'B' BEING DISCHARGED

Vapour from tank 'A' is discharged by compressor (c) into tank 'B' raising the pressure thereby forcing the liquid up the liquid line into the pump (P) which boosts the discharge pressure and sends the liquid ashore. Because vapour in vapour space is supersaturated, condensation takes place continuously and a warm thermal layer forms on top of the liquid.

CHAPTER II: GENERAL OPERATING PRINCIPLES

The cargo system of a typical semi-refrigerated gas carrier consists of number of cylindrical tanks strong enough to withstand the maximum pressure of the cargo it is intended to carry at the maximum carrying temperature envisaged. If, for any reason, the pressure rises above this limit, then safety valves lift and relieve the excess pressure.

The arrangement of the pipework in the cargo tanks is depicted in Fig. 2 and consists of:

(a) liquid line through which the liquid gas is loaded and discharged. It leads to the bottom of the tank.

(b) A vapour line through which vapour is withdrawn from the top of the tank, and which leads to the compressor suction.

(c) A condensate spray line which has the multiple function of:
   (i) Returning condensate from the condenser to the tank when it is being refrigerated. The returned condensate is usually sprayed into the tank through the upper spray.

   (ii) As a vapour line connected to the discharge side of the compressors, and through which the tank can be pressurised for discharging purposes.
   (iii) As a spray line to reduce pressure when loading. It will be noticed that there are two spray lines-the upper spray which is fairly coarse, and a much finer middle spray. The holes in the middle spray line are directed upwards, and the middle spray line is used to pre-cool the tanks when it is intended to load a very cold cargo.

(d) A relief line which leads up the mast, and to which at least 2 safety valves are placed in parallel to relieve excess pressure from the tank up the mast.

The general nature of the operation is to ensure that the ship may be loaded and discharged, the cargo cooled on passage, and the system be gas-freed, either for drydock, or when it is decided to change the type of cargo to be carried, and to this end, the vessel is fitted with compressors, cargo pumps, condensers and heat exchangers in the pumproom.

Loading

This is effected by loading via the liquid line into the bottom of the cargo tanks. As each tank fills up, the vapour trapped in the space above the incoming liquid is compressed, becomes supersaturated and condenses. However, in order to condense, it must condense on to something - usually the tank sides-but, particularly in the last stages of filling a tank when the space above the liquid is rapidly diminishing, the rate of condensation may not keep pace with the rate of compression, and the pressure in the tank starts to rise quickly. This build-up of pressure can be relieved by spraying liquid into the tank through the spray line which will provide myriads of small droplets and vastly increase the surface area upon which the supersaturated vapour can condense, or the pressure can be relieved by refrigeration. If all else fails, the excess pressure can be allowed to escape into another tank. In this latter case, the usual cause is the unsuspected presence of incondensibles.

Discharging

To discharge the ship, one (or more) compressor is started up in the pumproom, and the tank to be discharged is pressurised with vapour withdrawn from another tank or tanks, not being discharged, and sent via the condensate line to the tank being discharged whose liquid is blown "soda-water siphon fashion" to the cargo pump suction.

When the vessel arrives alongside after a period at sea, the "on arrival" tank pressures may be taken as very closely corresponding to the S.V.P. (saturated vapour pressure) of the product in the tank at the "on arrival" temperature. When, due to pressurisation, the pressure On the pump suction has been increased to about one bar above the "on arrival" pressure, the pump is started up. As the pump begins to operate, the pressure on the pump suction drops slightly. If there is any risk of the pressure on the pump suction falling below the S.V.P. of the product being discharged, the pump must be slowed down. If the pressure on the pump suction does fall below the S.V.P., the liquid in the pump suction will "flash" (vaporise), and the pump gas-up, which is the equivalent of an ordinary pump becoming "air-locked".

During the discharge, the vapour in the tank being pressurised for discharging purposes, will be super-saturated, so that condensation will take place continuously. Heat will be released, and the cargo will be steadily warmed. Fortunately, the heating effect due to the release of latent heat of condensation warms the top of the liquid in the tank, and as the specific gravity of the heated liquid will be less than that of the colder cargo, the warm liquid will tend to float on top and not to circulate by convection, so that it forms a thermal barrier about 30 centimetres thick. Nevertheless, the temperature of the cargo before it enters the pump suction should be watched-if no thermometer is fitted before the pump suction, then the one at the liquid discharge manifold will give an equally good indication and an allowance made for an increase of the S. V. P., if the temperature does rise.

When the warmer last 30 centimetres of liquid reaches the pump suction, the pump frequently gases-up. If this occurs, the warmer liquid should be transferred by difference of pressure to another tank (preferably the smallest and highest tank in the ship) which has sufficient space to receive the drainings (see Chapter IV). This is easy because, being pressurised, the liquid remaining will quickly move to an unpressurised tank. A small elevated tank is nearly always used because the concentration of warm drainings in this tank will:

(a) give the maximum sounding (depth) of liquid, which makes for easier priming of the cargo pump;

(b) if necessary, it can easily be refrigerated by using this tank as a vapour supply source to supply any other tank being pressurised for discharge purposes;

(c) being relatively elevated, it is easier to discharge (if it were situated above the cargo pump, it would not require pressurising).

If a vapour return line is provided at the discharge terminal, then vapour from shore can be used to pressurise the tanks being discharged instead of taking vapour from tanks not being discharged.

Refrigeration

In this operation, vapour is withdrawn from the top of the tank being cooled, compressed, condensed and returned as a, liquid via the condensate line to the same tank. The withdrawal of vapour from the tank being cooled reduces the vapour pressure in this tank to below the S.V.P. of the liquid in the tank. As a result of this, the liquid inside the tank bolls to replace the withdrawn vapour, latent heat is given up and the liquid in the, tank, so cooled.

The withdrawn vapour will be roughly at tank temperature, and is sucked through a heat exchanger, which also acts as a liquid trap. (It is, essential that no liquid enters the compressor suction, because, being non-compressible, on the compression stroke damage could be done to the compressor when the piston suddenly hits the liquid.) From the heat exchanger, the vapour then, goes to the compressor, compressed and discharged into the condenser, where it condenses.

Due to the adiabatic increase in temperature due to compression, the temperature of the vapour discharged is usually between 100 deg C. and 130 deg C., and is undersaturated. When it passes into the condenser the cooling water (seawater) first removes "sensible heat" from the hot vapour until it becomes supersaturated. The supersaturated vapour now condenses and surrenders latent heat. The cooling water is heated by the surrendered sensible and latent heat and is then discharged over the side to be continuously replaced by fresh cold water supplied by the condenser pump/s (usually situated in the engine room).

The resultant condensate will be at a temperature somewhat above sea temperature. (In fact its temperature will conform to the condenser pressure, but this in turn is affected by the efficiency of the coolant.) The condensate then passes through a number of tubes inside the heat exchanger where it is cooled by the incoming cold vapour withdrawn from the tank, which, in turn, is warmed by the condensate. The cool condensate is then allowed to pass back to the tank being refrigerated via a float-operated control valve into the condensate line, and so back to the tank by the sprays.

It would be possible to cool the cargo by allowing the vapour to escape up the mast (which would be wasteful and harmful to the environment), or, as in the case of methane carriers, to burn the "boil-off" in the ship's boilers.

Reliquifaction of the vapour is really a product-recovery system. Refrigeration takes place inside the tank and reliquifaction is an essential part of the process. However, in practice, reliquifaction is so closely bound up with refrigeration that the term refrigeration is often used instead of reliquifaction.

Gas-freeing

To gas-free the ship, the first step is to expel all trace of liquid from the tanks, pipe lines, cargo pumps and condensers by purging them over the side (i.e. allowing the residual vapour pressure in the tanks to blow out all traces of liquid). When this is done, the compressors are used to create a vacuum in the cargo tanks, line, condensers, etc., after which the vacuum is broken allowing air to enter the tanks. The tanks are then flushed through with air until each tank indicates that it is gas-free on the explosiometer. A second vacuum is then created and the whole system flushed through again. The procedure is then repeated, after which the ship may safely be considered gas-free.

CHAPTER III: CARGO HANDLING EQUIPMENT

The cargo handling equipment comprises:

- Cargo pumps
- Compressors
- Condensers
- Heat exchangers
- Vaporisers
- Cargo heater

The pumps and compressors are driven by electric motors situated in the motor room - a compartment pressurised with fresh air provided by one or more fans to exclude the possibility of the entry of gas from the pumproom. An electrical trip combined with a timer switch prevents the starting of any of the cargo handling equipment unless the ventilation has been in service for a specified length of time, and stops the plant if for any reason the ventilation is stopped. In the descriptions that follow, particular types of pumps and compressors etc. are described though the general principles are the same for all.

Worthington Cargo Pumps

The cargo pump, of which there will be more than one, is driven by an electric motor in the motor room, driving through a hydraulic clutch coupling, situated in the motor room, but with the control lever in the pumproom. The drive passes through a gas-tight bulkhead seal into the pumproom itself where it drives a multiplier-gearing which drives the pump.

The multiplier has its own lubricating system supplied by an electric pump in the motor room, which must be started prior to starting the main cargo pump.

The cargo pump's main bearings and the multiplier gearing system are water cooled; the pump main bearings are lubricated by a small lubricator. The pump seal is methanol cooled, and the cargo pump itself is cooled by the liquid it is pumping . For this reason, on no account should the pump be run unless it is actually pumping, not even at slow speed for test purposes.

The safety devices fitted are a high-pressure cut-out which will stop the pump if the discharge pressure exceeds 19 bars, and the pump cannot be started if the lubricating pump is not already running.

There is no over-speed cut-out, so that if the pump races (cavitates due to loss of suction), it must be stopped immediately.

Loire Compressors (6-cylinder)

A schematic arrangement of the compressor showing the suction and delivery arrangements is shown in Fig. 7. The suction and delivery valves are on separate plates which are concentrically arranged, the suction plate being on the outside, and the delivery valves in the centre. The two sets of valves are separated by a sleeve so that the lower gallery acts as a suction gallery, and the upper gallery acts as a delivery gallery. A series of dished washers act as a strong spring which, together with a strong pin, holds the delivery plate in position. In the event of a "slug" of liquid entering the compressor, the washers will be flattened, permitting the whole delivery plate assembly to lift, and so save the cylinder head from shattering.

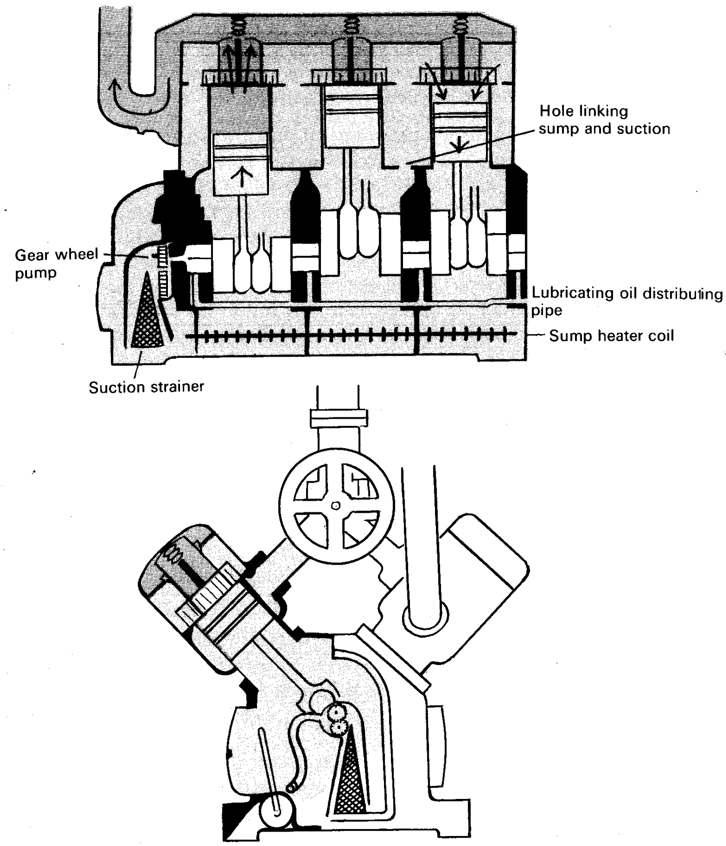


Fig. 7: Loire compressor

The cylinder block is hollow into which the cylinder sleeves are fitted. This cylinder block acts as a suction chamber for the gas handled by the compressor. The cool gas coming from the tanks flows around and over the cylinder sleeves thereby cooling them. Two holes bored through the cylinder block in the vicinity of the centre cylinder sleeve connects the suction with the crankcase so that the pressure in the crankcase always approximates to the pressure at the compressor suction, thus obviating any build-up of pressure in the crankcase due to slack piston rings.

Each compressor is fitted with 4 cylinder off-loaders which make it possible to run the compressor using 2, 3, 4, 5 or all 6 cylinders. These off-loaders work by holding open the suction valves when the cylinder is being off-loaded. They are operated by oil pressure.

An automatic-starting by-pass enables the compressor to be started up without any load. It is situated on top of the compressor between the "V" of the cylinders. It consists of a piston in a cylinder which acts as a circulating valve when in the open position by connecting the suction and discharge sides of the compressor. The piston is held in the open position by a spring, and lubricating oil acting on the other side of the piston opposes the spring. When the compressor is started up, the lubricating oil pressure is zero, so the spring holds open the circulating valve. As the oil pressure builds up, the oil pressure opposing the spring overcomes the spring tension and forces the piston back, thereby closing the circulating valve and putting the compressor on load.

The compressor discharges through an oil separator which traps any oil which is carried over by the discharged gas. The oil so saved is returned to the compressor crankcase under the pressure of the discharged gas throng either an automatic float-operated valve or by a manual by-pass, but neither of these valves should be opened until the bottom of the separator is hot (see section on Lubrication, immediately following).

Lubrication. A gear wheel lubricating oil pump is situated at the end of the compressor opposite the fly-wheel. The two gear wheels are fitted one above the other, the lower gear wheel being keyed directly to the crankshaft. The oil is sucked through a conical suction strainer and discharged via an oil cooler, through a filter, and then into the distributing pipe which feeds the crankshaft bearings and the shaft seals. The crankshaft has holes drilled in it which conduct the oil to the big end bearings. From the big end bearings, the oil passes up through a hole in the connecting rod to the little end bearings at the top. The cylinder itself is splash-lubricated. The oil pressure is regulated by a spring-loaded relief valve which is externally operated. The excess oil pressure is relieved by spilling back into the crankcase and is so adjusted as to maintain the oil pressure at about 2 bars above the crankcase pressure.

An oil heater is fitted in the sump of each compressor. Its function is, by heating the oil, to drive off the vapours which tend to dissolve into the oil when it is under pressure, in much the same way as carbon dioxide dissolves under pressure in water to make soda-water. With hot oil, very much less vapour can be absorbed than is the case with cold oil, and this is the reason why oil should not be returned from the oil separator until it is hot.

The oil heater is a finned coiled radiator and is supplied with hot water from a steam-heated tank.

Each compressor is fitted with the following safety devices:

1. lubricating oil differential pressure cut-out;
2. overheat cut-out;
3. high-pressure cut-out;
4. lubricating oil temperature cut-out;
5. safety disc.

1. Lubricating Oil Differential Pressure Cut-out This device stops the compressor if the oil differential pressure falls below a safe limit(usually set at 5 bars).

2. *Overheat Cut-out* The sensor for this device is attached to the compressor's discharge pipe, and stops the compressor if the discharge temperature exceeds 130 deg C.

3. *High-pressure Cut-out* This stops the compressor if the discharge pressure becomes excessive, generally due to a valve being shut on the discharge side. The actual setting can be adjusted but is usually at about 17 bars.

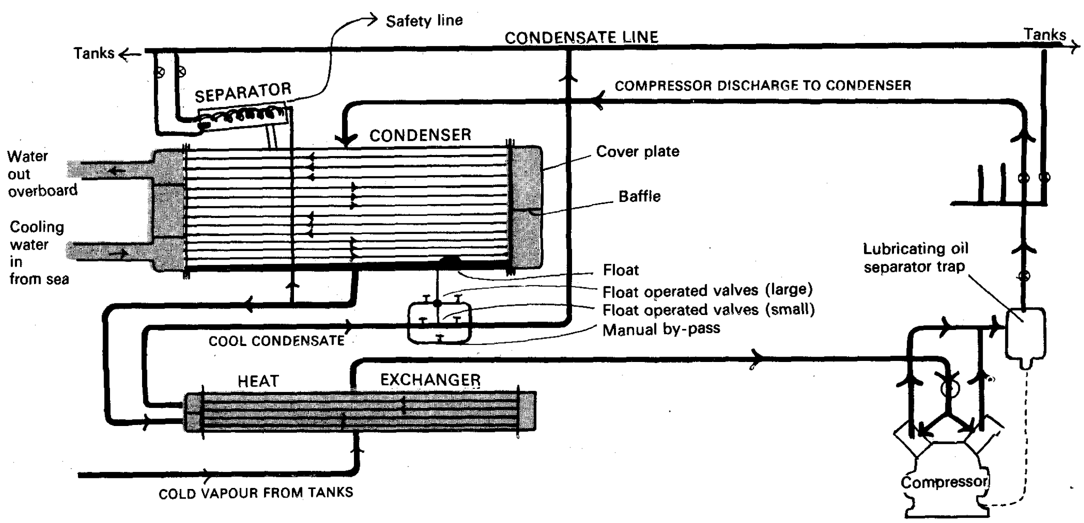
4. *Lubricating Oil Temperature Cut-out* This prevents the compressor from being started if the oil temperature is below 30 deg C. and stops the compressor if the oil temperature rises above 700 deg C.

5. *Safety Disc* This device virtually duplicates the high-pressure cut-out. It replaces the older type, "bursting disc" and is a spring-loaded valve between the suction and the discharge sides of the compressor. It operates on a pressure differential between the suction and discharge sides of the compressor. When the disc operates, it causes the compressor to circulate and will stop the compressor on the over-heat cut-out.

Condensers (Figs. 8 and 8A)

A condenser consists of an outer vapour shell, through which pass a large number of small galvanised steel tubes. On the vapour shell are bolted the end plates into which are incorporated baffle plates so that the seawater coolant zigzags its way through the tubes.

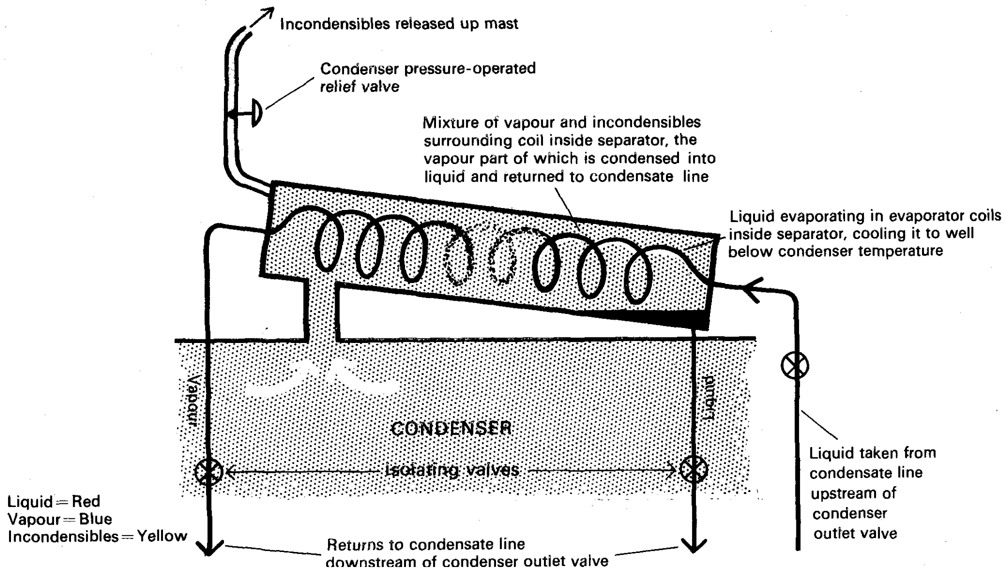
Fig. 8: Single stage refrigeration
Based on diagrams in Loire Handbook



Vapour is withdrawn from cargo tanks, through heat exchanger to compressor, and discharged from compressor into the condenser where it is cooled and liquified, the condensate passing back through the heat exchanger to the float-controlled regulating valve into the condensate line and back into the tanks.

The hot vapour discharged under pressure from the compressor is cooled by the seawater passing through the condenser tubes, and when it becomes supersaturated, condenses and forms a liquid at the bottom of the condenser. The sensible heat surrendered by cooling the vapour and the latent heat surrendered by the condensing vapour heats up the seawater, which passes over the side. Most of the heat given up is latent heat due to the vapour condensing, and not the sensible heat occasioned by a reduction of the vapour temperature. As the condenser works on the vapour almost exclusively and has little effect upon the condensate, the level of liquid in the condenser should be kept as low as is practicable.

Fig. 8A: Incondensible separator or purge condenser



An incondensible separator is fitted on top of the condenser. The most likely incondensible to be met is air or nitrogen. As both air and nitrogen are lighter than most of the products carried (butane, propane, propylene etc.) the air tends to collect at the top of the condenser, and so passes up into the incondensible separator. A small quantity of liquid taken from the condenser outlet is evaporated in a coil inside the separator, thereby cooling it. Any condensable vapour which may be intermixed with the incondensible, will condense into a liquid and is returned to the tank which is being refrigerated by the condensate line. As the temperature in the incondensible separator will be much lower than in the condenser, even semi-incondensibles such as ethane can be recovered in this way, and dissolved back into the cargo from which they originated. (This particularly applies when fully-refrigerated cargoes are carried, when the temperature in the separator can be expected to be very low.) This leaves only incondensibles in the separator. The presence of an undue quantity of incondensibles is indicated by a rise in the condenser pressure, and a reduction in the quantity of condensate made. When this occurs, the excess pressure due to the presence of incondensibles is released up the mast.

In "normal" circumstances, when few if any incondensibles are present, then the mast relief valve is kept shut, but the liquid return valve to the condensate line is kept slightly open. If this tank return valve were to be kept shut, any small quantity of incondensibles would get trapped in the condenser simply because they would not condense, and would have nowhere to go. Over a period of time, the condenser. would tend to fill up with incondensibles. With the tank return valve slightly open, any small quantities of incondensibles would be returned to the tank with the liquid condensate.

The mast relief valve is only used when the quantity of incondensible is excessive, and is indicated by the pressure in the condenser rising well above normal.

Heat Exchanger (Fig. 8)

The heat exchanger is similar in construction to a condenser. Essentially it consists of a number of tubes enclosed in a shell. The condensate from the condenser passes through the tubes, and the vapour from the tanks through the shell around them.

The heat exchanger is situated immediately under the condenser. Its main functions are:

(a) to act as a liquid droplet separator (liquid trap);

(b) to exchange heat between the warm condensate coming from the condenser, and the cold vapour coming from the tank, so that the condensate is cooled, and the incoming vapour warmed and dried.

The vapour coming from the tanks enters the heat exchanger at the bottom and leaves from the top, depositing any liquid droplets in the heat exchanger. Unless there is an undue quantity of liquid entrained with the incoming vapour, the warm condensate should evaporate them. A sight glass is fitted so that any build-up of liquid in the heat exchanger can be seen, and in some cases, a float-operated compressor cut-out switch is fitted which stops the, compressor should the level of liquid rise sufficiently to actuate it.

When the vessel is two-stage, refrigerating an atmospheric cargo (using 3 compressors, 3 heat exchangers and 1 condenser), additional arrangements must be made to control further the temperature of the vapour before it goes to the suctions of the compressors so that:

(a) very cold vapour coming from the tank is heated; and

(b) hot vapour discharged from the first stage compressors is cooled before going to the suction of the second stage compressor. (In this case, the heat exchanger is acting as an inter-stage cooler.)

The very cold vapour going from the tanks is warmed by conducting a small quantity of hot vapour from the first stage compressor discharge, and passing it through the inner tubes of the heat exchanger. The cold incoming vapour from the tanks liquefies the warm vapour (which is under pressure from the compressor) and the liquid so formed passed back to the tank via the condensate line, and the cold incoming gases warmed.

To cool down the hot vapours discharged from the first stage compressors before they enter the second stage (H.P.) compressor suction, some liquid is taken from the condenser and sprayed into the vapour line just before it enters the second stage heat exchanger (inter-stage cooler) to allow a small quantity of liquid to form in the bottom of the heat exchanger itself, but in such a manner as not to rise above a safe level. The temperature will conform to the pressure in the heat exchanger (usually between 3.5 and 4 bars). The level in the heat exchanger is regulated by a simple float valve. (See Two Stage Refrigeration, Chapter IV.)

Vaporiser

See Chapter VII.

Cargo Heater

The cargo heater permits the discharge of a cold cargo at atmospheric pressure into pressure storage ashore. It is in effect a heat exchanger where the cold product is warmed as it passes through the inner tubes by seawater which zigzags its way through the outer shell of the heater. 540 tons of water per hour are passed through the cargo heater and the cargo speed is adjusted so that the outlet temperature of the product being discharged is satisfactory.

If the outlet temperature of the seawater falls below 5 deg C., the cargo pump is stopped to prevent the risk of the heater icing up. (See Chapter VII for diagram and further information.)

CHAPTER IV: CONDUCT OF CARGO OPERATIONS

All cargo operations must be conducted within the framework of the General Principles described earlier. Cargo operations fall into two main categories, namely, semi-refrigerated and fully-refrigerated at atmospheric pressure.

SEMI-REFRIGERATED OR PRESSURE CARGOES

Loading

This operation follows the general principles very closely. The shore loading hose, and, if available, the vapour return line hose, are connected to the liquid and vapour line connections at the cargo manifold. Loading is effected through the liquid line, and pressure relief, etc., through the vapour return line. When the vessel arrives at the loading terminal, her tanks should be:

(a) empty of liquid, but under suitable pressure of vapour from her previous cargo (gassed-up); or

(b) gas-free, but under the maximum vacuum possible (usually in the vicinity of 80 per cent.). An increasing number of terminals insist that the vessel's cargo tanks be inerted before the final vacuum is created prior to loading.

If the vessel's cargo tanks are full of vapour at a suitable pressure (gassed up), loading can start at once. This being the simpler of the two cases given above, it will be described first. As the liquid enters the tank, the vapour trapped in the space above the liquid will be compressed, become supersaturated and condense. If a vapour return line has been provided, any excess pressure can be returned ashore. If no vapour return line is provided, then the pressure can be relieved in the following ways: firstly, by spraying part of the cargo into the tank, secondly by refrigeration and finally, if these methods fail, by allowing the excess pressure to escape into another tank. In this connection, it is not advisable to attempt loading all the, cargo through the sprays because to do so places an unnecessary restriction on the line. The sprays should be used only for the purpose of providing a larger surface area upon which the supersaturated vapour condenses.

In the second case, when the vessel arrives alongside gas-free and under an 80 per cent. vacuum, the first step is to break the vacuum with vapour taken from shore, and raise the pressure within the tanks to a suitable level. If a vapour return line is provided, this is simple. If no vapour return line is provided, the cargo tanks can be gassed-up by either using the vaporiser, or by spraying very small quantities of liquid into the tank via the fine spray line in such a manner that the liquid droplets evaporate before they come into contact with the tank's sides.

This effectively gasses-up the tank, but if the ship arrived with an 80 per cent. vacuum, 20 per cent. of the ship's capacity will be occupied by incondensibles at atmospheric pressure, the incondensibles being either air or inert gas (usually nitrogen).

However, under pressure, the physical space occupied by these incondensibles is much less. For example, under 3 bars pressure (gauge) they would occupy a quarter of the space they would occupy at atmospheric pressure. If the incondensibles remaining in the tanks consist of air, the atmosphere within the tank will be very "over-rich" after gassing-up, but to dispose of the incondensibles by the separator using the reliquifaction process involves putting a gas/air mixture through the compressors which involves a risk, however small, of an explosive mixture being passed through the compressors.

For this reason, some refineries insist on the cargo tanks being inerted prior to creating the final vacuum before loading, but many loadings have taken place over a long-period without any accident being attributed to this cause, and the danger may be more the theoretical than real.

The usual loading programme is to load the lower tanks first, and to complete loading in the upper tanks. The loading rate depends upon the diameter of the liquid lines and the number of valves open. When the number of valves opened towards the completion of cargo is reduced, the loading rate should be reduced accordingly. Soundings of all tanks should be checked at regular intervals to ascertain the loading rate, and also to ensure that no liquid is entering a tank which has been completed, or not started. This is very important because it is an old maxim that it is the unmatched tank which always overflows.

To load a very warm cargo from fully pressurised storage at ambient temperature into a semi-refrigerated ship, the reliquifaction plant must be started up and run at its maximum capacity to cool the cargo as it comes on board. The usual technique is so to adjust the loading rate as to maintain a pressure in the tanks below the safety valve relief setting. This can be achieved by maintaining a constant pressure at the loading manifold by frequently adjusting the manifold valve. Experience will soon show the best pressure to maintain and it is usually very close to the maximum pressure at which it is intended to load the product. The loading manifold pressure gives a much better indication of the valve adjustment needed, than watching the tank pressures, and adjusting the loading rate by guesswork.

Discharging

The pressures in the tanks at the time of arrival at the discharging berth are noted, and these can be taken as approximating very closely to the product. If the product has been refrigerated on passage, the liquid in the deck lines may be at a far higher temperature than the product in the tank. The most practical way to cool the product in the deck lines is to open the valve of one of the tanks before pressurising it

The drop in pressure in the deck line will cause the liquid in that line to boil and use up latent heat until its temperature falls to the same level as the temperature of the liquid in the tank.

While the discharge hose and vapour return line, if available, are being connected to the cargo manifold, the tank soundings, pressures and temperatures are checked and recorded by the cargo receiver's representative. When all is ready, one or more compressors are started up, and taking vapour either from the vapour return line, or from a tank or tanks it is not intended to discharge right away, the first tanks to be discharged (usually the two upper ones) are pressurised. Their tank valves and the pump suction valve are opened, and the liquid in the tanks forced to the pump suction. Any vapour trapped in the liquid line is released up the mast through the pump purges until the pump is full of liquid. When the pressure on the pump suction is about 1 bar above the S.V.P. of the product in the tanks, the discharge valve on the cargo manifold is opened and the vessel ready to discharge, and the shore advised. The pump is started with the discharge valve shut. As the pressure on the discharge side of the pump builds up, the discharge valve is opened slowly and the pump speed slowly increased. At the start, slugs of hot liquid and vapour can be expected. These are indicated by a flickering of the discharge gauge needle, but this steadies up once the cold liquid from the tank arrives, and the pump settles down.

The needle sometimes flickers towards the end of discharging a tank. This is due either to a shortage of vapour with which to keep the tank pressurised, or to a rise in the temperature of the product in the tank being discharged caused b condensation and release of latent heat in the tank. In either case, the pump should be slowed down, and, if possible, the pressure increased on the pump suction by putting an additional compressor into service.

Occasionally, it is very difficult to get the cargo going ashore at all. Everything is going correctly until the moment the discharge valve is opened, when the pump gasses-up. This is usually due to a very high back pressure ashore, combined with a large quantity of vapour in the shore discharge line. The best way to overcome this problem is to shut the liquid discharge valve on the cargo manifold, and then pump for a few seconds, transferring some liquid from one tank to another. This fills the line on the discharge side of the pump with liquid which, when the cargo manifold is next opened, will act as a buffer and prevent the pump being gassed. Because the tanks are almost full, only the smallest quantity of liquid should be transferred, but a well trained operator can usually change over from discharging into a tank to discharging ashore without stopping the pump.

The tanks are drained by difference of pressure using the compressors, usually into one of the upper tanks. For this reason, the tank selected to receive the drainings from the other tanks is not completely discharged. It is then used as one of the vapour sources from which vapour is withdrawn by the compressors to pressurise the tanks being discharged, so that it is kept cool and at a low pressure, which will facilitate the transfer of drainings.

This is done as soon as a pair of tanks has been discharged as far as the pump is capable, and whilst they are still pressurised.

The tank containing the drainings is pumped out at the end of the discharge, and if reasonably elevated, empties almost completely before the cargo pump loses its suction.

The routines for measuring the cargo, and the methods of calculating the quantities loaded or discharged are discussed in Chapter IX-Cargo Calculations.

Refrigerating the Cargo (Figs. 8 and 8A)

After ensuring that water is passing through the condenser, and there is no liquid in the heat exchanger, the vapour lines are set to suck vapour from the tank to be refrigerated for discharge into the condenser. If the presence of incondensibles is suspected, any excess pressure in the condenser must be at once relieved up the mast via the incondensible separator. If there is no sudden build-up in pressure in the condenser and liquid forms readily, it is usually sufficient to I allow what few incondensibles that may be present to circulate back to the tank by leaving the incondensate circulating valve slightly open.

The compressor is started with the discharge valve open, and the suction valve shut. The pressure on the compressor suction is allowed to come down to a vacuum, and then the suction valve is opened slowly. The rise in pressure in the condenser is closely observed (see end of this Chapter). Once the condenser pressure has steadied and is reasonable, liquid should start to form in the condenser The condenser outlet valve (expansion or regulating valve) is set to "automatic". The condensate will then start to pass back to the tank being refrigerated via the condensate line. If during the refrigeration process, an undue quantity of incondensibles arrives in the condenser, this is indicated by a rise in the condenser pressure, and a fall in the production of condensate made. The excess pressure occasioned by the presence of incondensibles must then be relieved up the mast.

In this connection, some vessels are provided with an automatic incondensible relief valve. The relief setting can be varied and is set at between 0.5 and 1 bar above the normal operating pressure of the condenser, which varies with the temperature of the cooling water for any given product and between different products.

In a vessel capable of both semi-refrigeration and full refrigeration, it is normal for the condenser to be provided with two liquid outlet valves (usually referred to as expansion valves, although this is not their true function, the expression "expansion valve" being taken from the refrigeration terminology), each controlled by the same float controller. These outlet valves are of two different sizes. The large valve is used when semi-refrigerating, the smaller when using two-stage refrigeration. This is because much more condensate is made with a relatively high suction pressure (semirefrigerating) than with a low suction pressure (two-stage) because, although the volume passed by the compressor is constant, if the suction pressure is greater, then a greater quantity of vapour is passed through.

Gas-freeing

The first step is to check that the condensers are empty of liquid (blown down). Then a flexible hose is rigged over the stern, connected to the stern liquid line.

The object of-the next stage is to free the ship of all residual liquid lying in the tanks, pumps, liquid lines, etc. This can be done in two ways. If there is sufficient vapour pressure remaining in the ship, the first way is the quickest, which is to open all the pump suction valves, cargo heater isolating valves, all valves in the liquid line, and the cargo tank valves, and allow the pressure in the cargo tanks to blow all the liquid remaining in the ship over the stern.

If there is insufficient pressure in the cargo tanks to do this (e.g. after discharging a fully refrigerated cargo at about atmospheric pressure), then the second method must be used. In this method, the cargo tanks are warmed by using the compressors to circulate vapour by withdrawing it from the top of the tanks, and by discharging it into the liquid line, return it to the bottom of the same tanks. The vapour is warmed by passing through the compressors, and the warm vapour evaporates the small quantity of liquid remaining in the bottom of the cargo tanks.

However, before this part of the operation is commenced, the liquid remaining in the liquid line is first blown over the stern by the compressors discharging into the liquid line and out through the flexible hose connected to the stern liquid line. If this is omitted, then the liquid remaining in the liquid lines after discharge will be swept into the cargo tanks, and the tank warming operation prolonged. To change over from blowing over the stern to tank warming, the tank liquid valves are opened and the stern discharge valve shut.

It is usual to warm the tanks in pairs, and it takes from 4 to 6 hours to evaporate the residual liquid in each pair of tanks. The evaporating process will cause a slight rise in pressure in the cargo tanks. When all the liquid in the tanks has been evaporated, any excess pressure is released over the stern, the stern valve shut, and the flexible hose recovered.

The next stage is to create a vacuum on the whole cargo system by arranging for the compressors to draw vapour from the tanks and discharge up the mast to atmosphere. This is. one to expel the bulk of the vapour. Once the vacuum has been created, it is broken with air by opening one of the valves on the cargo manifold. Here, the technique varies according to the product previously carried-L.P.G. or ammonia.

Because L.P.G. vapour is heavier than air, the compressors, sucking air from the atmosphere via the vapour line connection on the cargo manifold, discharge it into the tops of the cargo tanks, and flush out the L.P.G. vapour from the bottom via the liquid line, and over the side via the lee liquid valve at the cargo manifold. It is a good scheme to open the condenser valves so that part of the air flows through the condensers and gas-frees them. At the start of this operation, that part of the vapour line between the manifold and the compressor suction will contain a gas/air mixture which will have to pass through the compressor. It is vitally important that this gas/air mixture is discharged freely and not be subject to compression. For this reason, it is advisable to discharge for a few minutes up the mast until that section of the line and the compressors have gas-freed themselves. A constriction on the compressor discharge (due to a valve having been left shut inadvertently), will cause a pressure build-up, and it has been calculated that, at 14 bars discharge pressure, the adiabatic increase in temperature due to compression equals the ignition temperature of L.P.G. gases, and combined with a "flash back" into the condenser, a serious explosion has been attributed to this cause. Gas tanker operators refer to an explosion brought about by the adiabatic rise in temperature due to compression as "the diesel effect".

After the tanks have been flushed through for some time each tank is ventilated separately and the outflow tested at the liquid line outlet until it shows gas-free on the explosiometer, the explosiometer being a portable instrument which measures the percentage concentration of gas in air. When each tank in turn shows that it is gas-free, a second vacuum is created, the vacuum broken and the tanks flushed through, again and a third vacuum created, when the ship may be said to b6 gas-free. The second and third vacuums are created in order to diminish the strength of any gas/air mixture lurking in a cul-de-sac and which has escaped dispersal during the flushing through operations.

Although the vessel is gas-free, it is usual to ventilate daily to disperse any gas concentrations forming in the bottoms of the tanks due to subsidence.

In the case of ammonia, two 70 per cent. vacuums are created and broken in succession. The first vacuum reduces the vapour/air mixture to 30 per cent., which is over-rich. The second vacuum reduces the ammonia concentration to 9 per cent., which is -too lean to cause an explosion. The tanks are then ventilated by sucking from the top of the tanks, and allowing the air to enter the tanks at the bottom via the liquid line by opening the liquid valve on the cargo manifold. The vacuums can be created and broken and the tanks ventilated merely by operating this one valve, without stopping the compressors. This tank ventilation is continued until the concentration of ammonia in the tank atmosphere is below 100 p.p.m. (100 parts per million). Such a low concentration, although very easily smelt, can only be measured by, crystals changing colour chemically, using the same principle as a "breathalyser" and the instrument frequently used is the "Draeger".

Two more vacuums are then created and broken and the tanks ventilated for the same reasons as are given for gas-'freeing from L.P.G., but with ammonia, due to its contaminating influence upon other cargoes, shippers of L.P.G. cargoes demand virtually a total absence of ammonia vapour in the region of 5 to 20 p.p.m.

FULLY-REFRIGERATED CARGOES AT ATMOSPHERIC PRESSURE

Loading

This operation falls into two parts: pre-cooling and then loading. The procedure for a ship arriving at the loading terminal under vacuum, or for a consecutive cargo, are essentially the same, except that, when arriving under vacuum, the tanks will be warm and the cooling down procedure will take longer. The tanks must be cooled prior to loading because the tanks shrink during the cooling process, and this shrinking (contracting) process must take place whilst the tanks are empty. Whilst shrinking, the tanks will have to move in the support cradles, and to avoid placing unnecessary strain on the tank support system whilst this movement is taking place, the tanks should have no weight in them.
The tanks must also be cooled evenly and slowly (the cooling rate for any ship will be specified and can be expected to be about 6 deg C. per hour for this type of ship).

To cool the tanks prior to loading, liquid taken from shore is sprayed into the tanks via the fine spray line. The holes in this spray line are directed upwards so that the holes in them are less likely to get clogged, and the droplets of liquid moving first upwards and then downwards have more time to evaporate than would be the case if the holes were directed downwards.

Incondensibles present the same problem as described in previous paragraphs concerning loading semi-refrigerated cargoes. The spraying process is continued until liquid is firmly established at the bottom of the tank. The coarse sprays at the top of the tank should not be used for cooling purposes because the liquid droplets, being larger, will not evaporate so easily and liquid at the bottom of the tank form too quickly, causing uneven cooling and also create a cold thermal barrier at the bottom of the tank and prevent convection by subsidence.

If the shore does not provide a vapour return line, the reliquifaction plant can be used to relieve any build up in pressure during the pre-cooling and loading processes, and to release any incondensibles to the atmosphere.

When liquid is firmly established at the bottom of the tank, loading in bulk through the main liquid line may commence and procedure from this point is the same as for loading a semi-refrigerated cargo.

Discharging

With very low temperature cargoes, the liquid lines on deck must be cooled down prior to discharge, in the same manner described for cooling the lines described in the Section dealing with loading semi-refrigerated cargoes (i.e. to open a tank valve and allow the liquid in the line on deck to boil and so cool itself down to the same temperature as the product in the tank).

The principal difficulties to be overcome or minimised when discharging a fully-refrigerated cargo, as opposed to a semi-refrigerated cargo, are:

(a) to minimise the heating effect of pressurising the cargo tanks in order to discharge them, due to the release of latent heat by condensation;

and

(b) the insufficiency of vapour available in the tanks not being discharged to act as a vapour source with which to pressurise the tanks being discharged. This particularly applies when no vapour return line is discharged provided.

To commence the discharge, the first tank or pair of tanks is pressurised and the discharge commenced in the same manner as is used for semi refrigerated cargoes. If no vapour return line is provided, the available , vapour supply may be inadequate to keep the tank being discharged pressurised and if this occurs, the vaporiser must be placed in service to supplement the work of the compressors. The vaporiser produces large quantities of vapour, the temperature of which is determined by the pressure in the vaporiser, which will be a little higher than that of the tanks being pressurised.

Due to the heating effect of pressurisation and the limited supply of vapour available to keep the tanks being discharged pressurised, it is usually necessary to discharge the larger lower tanks half-way at first, then, using the pressurised tank as a vapour source, pressurise the second set of tanks and then discharge them half-way. Although the tank being discharged is heated by condensation, the tank or tanks being used as a vapour source are being cooled.

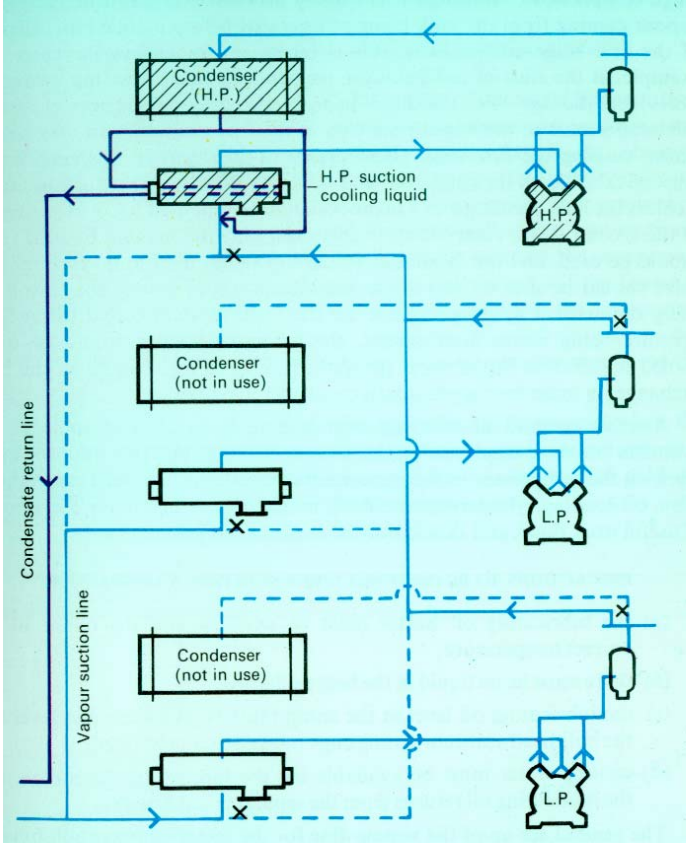
To keep the cargo as cold as possible whilst discharging, the general rule is, to take vapour from the tanks not being discharged whilst it is at all possible, and to take vapour from the shore, or use the vaporiser, as little as possible.

The order of discharge, therefore, usually works out as follows: first, discharge the two upper tanks, one of them completely, the other (which is reserved for receiving the drainings) about three-quarters. Then half-empty the two forward lower tanks using all the other tanks as a vapour source. After that, half-empty the two after-lower tanks and then go back to the two forward-lower tanks and completely discharge and drain them. After this, discharge and drain the two after-lower tanks and complete the discharge by emptying the tank used for draining.

Two-stage Refrigeration

In two-stage reliquefaction, one or more compressors in the first or L.P. or into the heat exchanger of the H.P. or second stage further raises the pressure and discharges into the vapour is condensed and returned to the tanks as a liquid in the normal manner, See Fig, 9.

Fig. 9: Two-stage reliquifaction using 3 single stage compressors



If the liquid coming from the tanks being refrigerated is very cold, it must be warmed and this is done by taking some of the hot gases discharged from the first stage compressor and feed them back into the inner tubes of the heat exchanger, where being under being under the pressure of discharge (about 3-4 bars), they liquefy and return to the tank via the condensate line.

The hot vapor from the discharge of the first stage compressors is discharged into the heat exchanger of the second stage compressor and is cooled by a small quantity of liquid taken from the condenser. Therefore the second stage heat exchanger acts as an inter-stage cooler. If this were not done, the second stage (H.P.) compressor would soon overheat.

When the liquid taken from the condenser is injected into the vapor line just before it enters the heat exchanger, most of it evaporates at once, so cooling the H.P., or second stage vapour suction. After a time, not all the liquid will evaporate, and a small quantity will appear in the heat exchanger. As soon as appreciable quantity of liquid gathers in the heat exchanger (or inter-cooler), a float-controlled valve shuts off the liquid, but opens again as soon as the level of liquid falls, thus acting as a regulating valve.

Because the second stage (H.P.) compressor will quickly overheat if the vapour suction is not cooled, it is important to spray in the liquid as soon as possible. For this reason, the condenser should not be emptied of liquid if refrigeration is suspended, in order that liquid will be readily available when refrigeration is resumed.

In two-stage refrigeration, it is usual to use two compressors in the first (or L.P.) stage, feeding one compressor using 2-4 cylinders in the second or H.P. stage. Two commence two-stage refrigeration, the second stage (H.P.) compressor, is started, followed by at least one compressor in the first stage (L.P.) as quickly as possible. It takes at least one compressor in each stage to make the system viable, because the H.P. compressor,, by itself, has no suction, and the discharge side of the L.P. stage is "blocked" unless the second stage compressor is running.

The principal cause of compressors cutting-out and stopping themselves during two-stage refrigeration is overheating. The best way to prevent this is to control the temperature on the suction side of both the first and second stage compressors. Although it is usually necessary to warm the very cold vapour coming from the tank being refrigerated before it enters the suctions of the first stage compressors, this is by no means always the case. For example, at the start of refrigeration, particularly when releasing incondensibles from the ship when the ship is being loaded after having been gas-freed, the temperature of the vapour arriving at the first stage suction may be too warm, causing the first stage compressors to overheat. In this case, liquid must be taken from the condenser and, sprayed into the vapour suction before it enters the heat exchanger in a manner similar to that used to cool the suction of the second stage, except that, in this case, only the manual by-pass valve should be used, and the minimum amount of liquid used to do the job; this valve should be shut off as soon as the system settles down. The reason for using the manual by-pass and not the automatic system is that the suction pressure being about atmospheric, the incoming vapour would be overcooled if sufficient liquid were sprayed in so as to form liquid in the heat exchanger in order for the automatic controller to work.

Another method of relieving over-heating is to off-load some of the cylinders on the compressor which is over-heating, but this imposes more work on the compressor in the opposite stage, and this may start to overheat. Also, off-loading cylinders (particularly in the first stage) reduces the amount of useful work done, and should only be used as a last resort.

PRECAUTIONS TO BE OBSERVED WHEN STARTING A COMPRESSOR

(a) the lubricating oil heater must be working and the oil be at the correct temperature;

(b) there must be no liquid in the heat exchanger;

(c) the lubricating oil level in the sump must be at the correct level and the bulkhead seal-lubricating cups full and the cocks open;

(d) cooling water must be available for the lubricating oil coolers and the lubricating oil returns from the separator must be shut.

The general set-up of the vapour line for the intended operation must be checked and, if satisfactory, the compressor discharge valve opened and the suction valve shut. The compressor may then be started. As soon as the pressure gauge on the suction side shows a vacuum, the suction valve is slowly opened, observing that the lubricating oil pressure rises as the suction pressure rises. The pressure indicated on the compressor discharge gauge must be watched to ensure that there is no constriction. If the discharge pressure rises abnormally, the compressor suction must be shut and the compressor stopped.

POINTS TO WATCH WHILST THE COMPRESSOR IS RUNNING

In addition to recording the suction and discharge pressures and temperatures, lubricating oil pressure, condenser pressure, seawater temperature, etc., the temperature of the compressor heads should be closely observed (by touch). If one of the heads is hotter than the others, this usually indicates that the compressor suction or discharge valves inside the compressor are failing. If the cylinder head is unduly cool, this indicates a "wet suction". A "wet suction" means that droplets of liquid are entering the compressor as a result of carry-over from the heat exchanger, which will be found to contain too much liquid. The droplets of liquid entering the compressor evaporate and remove most of the heat gained by the adiabatic process due to compression. The compressor must be stopped and the source of the liquid traced and corrected.

After the compressor has been running for some time, and when the bottom of the lubricating separator is warm, the automatic oil return valve should be opened. If the return valve is opened too soon, then cold oil, saturated with vapour, will be returned to the sump.

PART II

FULLY-REFRIGERATED SHIPS

CHAPTER V: GENERAL DESCRIPTION

The increase in size of Liquid Gas Carriers led to the development of fully refrigerated ships which carry their cargoes at about atmospheric pressure. Because the tanks in which the cargo was to be carried would no longer be subject to high pressures, as is the case in the fully-pressurised and semi refrigerated ships, the cargo tanks could be "box shaped" as opposed to spherical or cylindrical, so making better use of the space within the ship's hull. Additionally, the tanks could be made very much larger and, for any given size, much lighter. See Fig. 10.

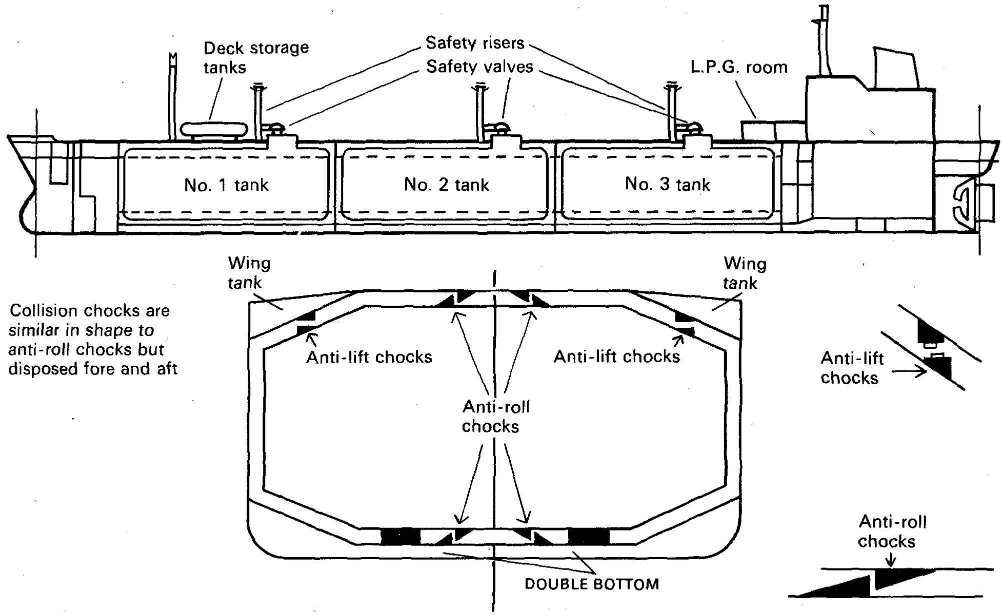


Fig. 10: Fully refrigerated L.P.G. tanker

To deliver the Product to the cargo pump suction, a new system had to be designed. This was the deepwell pump. Since the same design restrictions relating to no joints, glands, etc., being permitted below the level of the deck in fully-pressurised and semi-refrigerated ships apply also to vessels of the fully-refrigerated type, the design of the deepwell pump has to take this into consideration. The pump itself is located at the bottom of a cargo tank, connected by a long driving shaft to a flame-proofed electric motor situated on top of the cargo tank, the shaft passing through a gas-tight seal where it penetrates the tank dome, the dome protruding through the deck.

The deepwell pump supplies the main cargo pumps with liquid, and these pumps boost the pressure, and send the product ashore. In short, the deepwell pump performs the same function as pressurisation in pressure ships, but has the advantages that:

(a) it does not tend to heat up the cargo as does pressurisation due to condensation;

(b) it could lift the liquid to a much greater height than could be achieved by pressurisation, and so the tanks could be made deeper.

A natural development was to make the deepwell pump more powerful (multi-stage) with a discharge pressure of between 9 and 10 bars as opposed to about 2, and so obviate the necessity of always having to use the booster pump on deck. As the tanks became even deeper, the length of the driving shaft of the deepwell pump imposed certain limitations, and the submerged cargo pump was developed with electric motor inside the cargo tank, thus dispensing the long driving shaft.

A typical fully refrigerated gas carrying vessel would have three or four main cargo tanks, each constructed with a trunk space and a protruding dome through which pass all the pipes, driving shafts, tank measuring devices, pressure gauge connections etc. Each tank is fitted with a number of transverse wash plates which give added strength to the tank, and also cut down the surge effect of the vessel is pitching, and also longitudinal bulkhead which divides each tank in two so that each tank becomes a pair of tanks (port and starboard), but with a common vapour space at the top.

Each pair is fitted into a separate hold, or containment space, as the holds are called. The tank support system is designed so that the tanks may move to a limited extent to allow for the slight hogging and sagging movements of the hull when the vessel is in a seaway, and also to allow the cargo tanks to expand and contract according to the temperature of the product carried. These supports themselves are placed on solid floors and keelsons. Anti-roll chocks, anti-collision chocks and anti-lift chocks are also fitted.

As an added safety measure, the spaces surrounding the cargo tanks in the containment space are inerted so that, unless the hull is pierced, there is no risk of a fire or explosion in the containment space even if, due to leak drom the cargo tank, gas collected in this space.

All the cargo pipe lines and cargo tanks must be constructed of special steel ("Arctic D"), capable of withstanding low temperatures, as well as that part of the ship's structure surrounding the cargo tanks (virtually all the sides of the containment spaces), forming a secondary barrier to contain the cargo in the event of one of the cargo tanks being ruptured. Additionally, a means of emptying the containment spaces of any liquid product which has leaked in is provided.

In order to fulfil her role as a liquid gas carrier, the vessel must be capable of loading, carrying, discharging the cargo, and being gas-freed, either for dry-dock or to change the type of product to be carried. The cargo-handling system therefore comprises:

For Loading - A large diameter pipe leading from the main liquid line on deck to the bottom of each tank through which the liquid gas is loaded.

For Cooling the Cargo on Passage - A large refrigerating plant. In this connection, there are two methods of reliquifaction : two-stage and cascade. These systems are described separately, later. The reliquifaction plant is also used whilst loading, to relieve the build-up in pressure caused by the incoming liquid reducing the vapour space above the liquid level, thus compressing the vapour trapped in the space above the liquid.

For Discharging - A deepwell pump in each tank (one each side of the dividing bulkhead) to feed the booster pumps on deck, unless the deepwell pump is of sufficient power to dispense with the use of booster pumps.

For Gas-freeing the Ship-

(a) a puddle heating grid system in the bottom of each tank to evaporate the residual liquid remaining after discharge;

(b) an inert gas system for inerting the cargo tanks so that the vapour remaining in the cargo tanks after all the liquid has been evaporated can be displaced with inert gas with complete safety;

(c) a means of ventilating the cargo tanks with air to remove the final traces of vapour after the tanks have been inerted, and to make the tanks ready for entry, if required. (The inert gas system is also used for displacing the air with inert gas prior to loading.)

Some ships are also provided with a system whereby the vessel's cargo tanks may be filled with vapour whilst at sea. On deck there are separate liquid gas storage tanks of sufficient capacity that the liquid, when vaporised in a vaporising unit, can completely fill the ship's cargo tanks with a vapour compatible with the succeeding cargo.

The ships are usually provided with a cargo heater to enable the vessel to discharge into pressure storage ashore, and a booster pump if the discharge pressure is significantly above 9 bars.

Some ships are provided with a separate purge line system at the top and bottom of each tank. The purge lines form a grid with tiny holes in the pipes and are used to diffuse the inert gas evenly at the top of the cargo tank, and to collect the exuding vapour from the bottom of the tank, so eliminating the many pockets of vapour which would otherwise exist if the liquid and vapour lines alone were used for this purpose.

ADDENDUM

Cargo Tanks

These are built of special low temperature steel ("Arctic D"). They may be built in various shapes (prismatic) to make maximum use of the space available in the containment space into which they are fitted, but are so constructed as to minimise the free surface, effect by having a small surface area at the top. This usually, but not always, takes the form of a trunk space.

Each cargo tank is divided into two by a longitudinal bulkhead to further reduce the free surface effect, and is strengthened transversely by a number of wash plates, which also reduce the surge effects of the liquid in the tank when the vessel is at sea. At the bottom of the longitudinal bulkhead is a bulkhead valve which, when opened, enables the tank to be pumped out, using one pump only.

At the top of the tank is the tank dome which is the only part of the cargo tank which protrudes through the deck, to which the access hatch lids are attached, and through this dome pass all the pipe lines, etc.

The after-end of the cargo tank is usually provided with a pump well into which the cargo pumps are fitted.

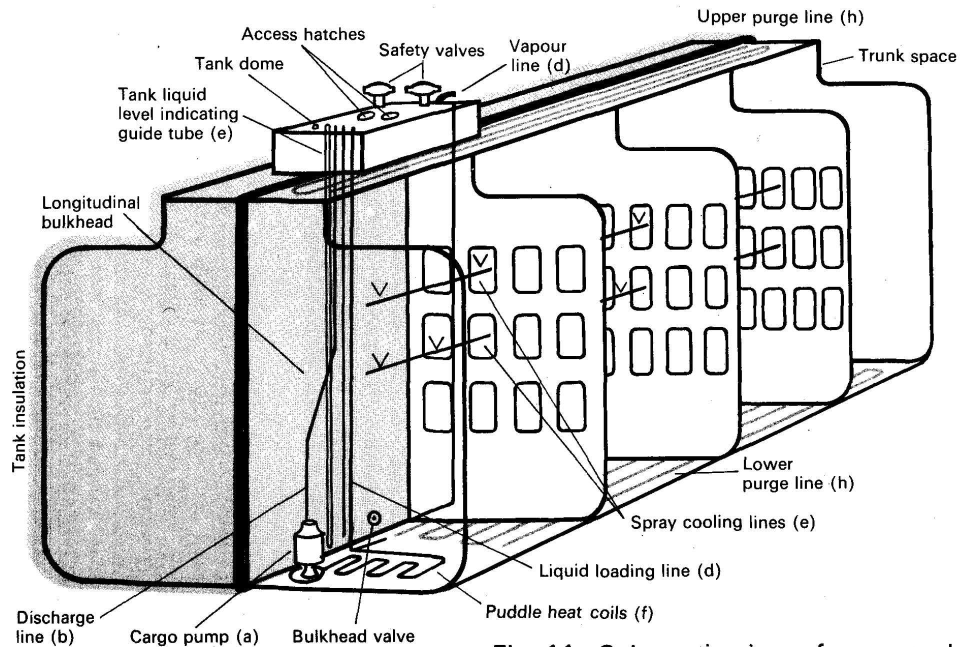


Fig. 11: Schematic view of cargo tank

Each cargo tank is provided with the following equipment (See Fig. 11):

(a) Two cargo pumps (one either side of the longitudinal bulkhead) at the after-end of the tank in the pump wells, discharging through

(b) The liquid discharge line which emerges through the tank dome and is connected to the main liquid line.

(c) An emergency pump trunkway into which an emergency cargo pump can be inserted in the event of both main cargo pumps failing.

(d) A liquid loading line connected to the main liquid line on deck and leading to the bottom of the cargo tank through which the product is loaded.

(e) A series of spray lines connected to the condensate line used for tank cooling purposes.

(f) A puddle heat grid system at the bottom after-end of the tank, used to evaporate the residual liquid when gas-freeing or changing grades.

(g) Two tank liquid level-indicating devices (one on either side of the longitudinal bulkhead). These usually consist of a float attached to a self-winding tape which moves up and down, either on guide wires or inside a guide tube, the liquid level being read off the tape through a gas-tight window at the top of and outside the tank.

(h) Two sets of purge lines (upper and lower) which form grids at the very top and the very bottom of the tanks. These purge lines have very small holes in them and are used to distribute evenly the inert gas or vapour fed into the tank and to collect evenly the displaced inert gas or vapour when gas-freeing or gassing-up the cargo tanks.

(i) A vapour line connected to the tank dome and through which vapour can be withdrawn by the compressors.

(j) A series of sample tubes for sampling the vapour when gas-freeing.

The cargo tanks are fitted with the following safety devices:

(a) At least two safety valves to relieve automatically any excess pressure in the cargo tank.

(b) High- and low-level alarms which give warning when the tank is nearly full when loading and nearly empty when discharging. They are operated by the liquid level-indicating device and emit alarm signals at soundings corresponding to 96 and 97 per cent. capacity when loading and at about 1 metre and 1/2 metre from empty when discharging. These alarms can usually only be silenced in the vicinity of the tank domes, so summoning the operators to their station if not already there.

(c) Overfill alarms. These are usually set at a depth corresponding to 98.5 per cent. capacity and, when actuated, usually shut the main loading valve and, sound an alarm.

Externally, the tank is covered with insulation (although an internal form of insulation has been developed). Underneath the insulation are fitted the temperature recording probes. These are usually of the resistance type, relying on the variation in the value of their resistance caused by changes in temperature. They are powered by electric current of very low voltage and register on a temperature recorder located in a cargo monitoring room.

CHAPTER VI: GENERAL OPERATING PRINCIPLES

Loading

The vessel usually arrives alongside at her loading berth with her reliquifaction plant running, and with her cargo tanks cooled down to the required temperature. her liquid lines through which the cargo is to be loaded pre-cooled and the pressure in her cargo tanks low (about 0.02 bar). Loading is effected through the liquid line into the bottom of her cargo tanks.

If the shore vapour line is provided, it is important to ascertain the conditions under which it is used. If the returned vapour is flared, the vapour return line should be used as sparingly as possible and only then to, relieve excessive pressures (usually, towards the end of loading) with which the reliquifaction plant is unable to cope. The running of the plant whilst loading is recommended because it serves to conserve product. In any case, it must be restarted when loading, is completed and kept running during passage.

The maximum safe loading varies from ship to ship, but is usually in the region of 500 Cubic metres per hour for each valve open. As the loading valves are shut when each tank is tilled to its correct level. the loading rate should be reduced accordingly.

Refrigerating the Cargo on Passage

In this operation. vapour is withdrawn from the top of the tanks to be refrigerated, compressed, condensed into a liquid in the condenser, and the condensed liquid returned to the tanks. The withdrawal of the vapour reduces the vapour pressure in the tank to below its saturated vapour pressure so that the liquid in the tank boils, latent heat given up and the tank therefore cooled.

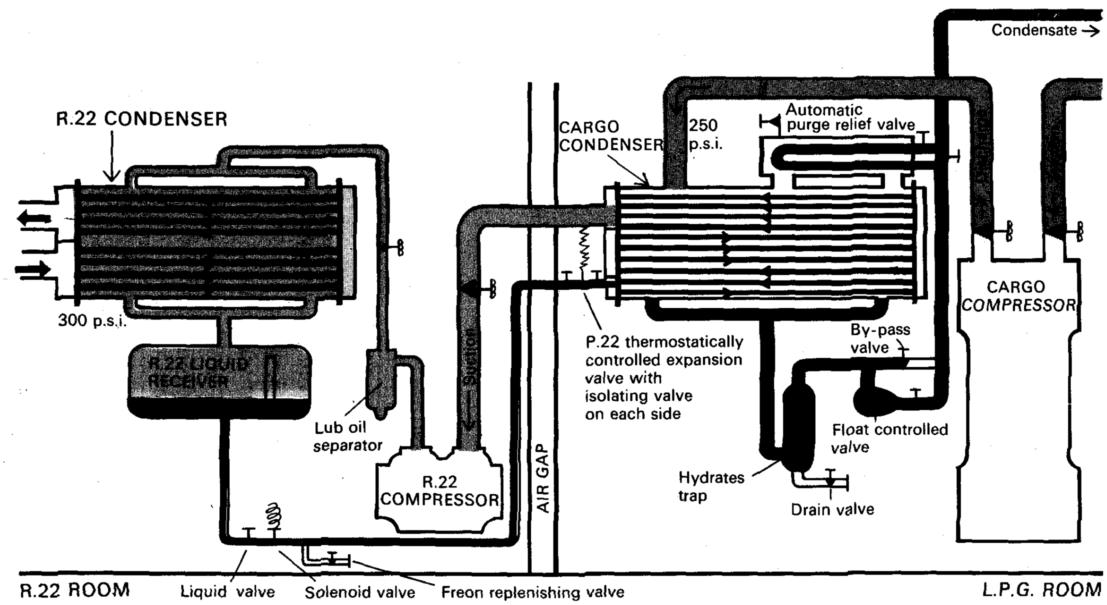
However, there are two types of reliquefaction systems, namely two-stage and the cascade systems.

In the *two-stage system*, the condenser is cooled with seawater. It requires a two-stage compressor to raise the pressure from about atmospheric pressure to about 15 bars, suitable for use with a seawater-cooled condenser.

A typical two-stage compressor is one with 8 pistons of which 6 are used in the first (L.P.) stage and 2 in the second (H.P.) stage. The vapour withdrawn from the tanks is sucked through a heat exchanger, which also acts as a liquid trap to the L.P. suction of the compressor from which it is discharged into the inter-stage cooler, where it is cooled by injecting liquid taken from the condenser, into the L.P. discharge pipe just before it enters the inter-stage cooler, reducing its temperature from about 70 deg to 30 deg C. From the inter-stage cooler, the cooled vapour is drawn into the second-stage (H.P.) suction and then discharged into the seawater-cooled condenser, where it condenses. The relatively warm condensate first passes through the inter-cooler and then into the heat exchanger before it escapes through a float-controlled valve back into the cargo tank via the condensate line. As soon as the condensate passes through the control valve, it experiences a drop in pressure from about 15 bars (condenser pressure) to about 0.5 bar. This sudden drop in pressure causes a proportion of the condensate to evaporate and, in so doing, the condensate cools itself down to approximately tank temperature, and a mixture of cold condensate and vapour is returned to, the tank.

If the condensate line were badly insulated, more of the condensate would evaporate to compensate for the temperature gained through the badly insulated line, until, if the line were so badly insulated that all the condensate were evaporated, the resulting cooling effect on the tank would be nil. The net cooling effect upon the tank being cooled is the latent heat of vapour withdrawn minus the latent heat of the vapour returned (or the latent heat of the liquid returned).

Fig. 12: SCHEMATIC DIAGRAM OF CASCADE SYSTEM OF REFRIGERATION



The cascade system of reliquifaction is shown in Fig. 12. In this system, a refrigeration unit using Freon 22 (R.22) discharges into a seawater-cooled condenser which condenses the Freon 22 into a liquid which passes from the condenser, into a Freon 22 tank where it is stored. Liquid Freon 22 passes from the storage tank as required into the cargo condenser where a thermostatically controlled expansion valve allows it to evaporate inside a series of tubes in the cargo condenser, so cooling it. The evaporated R.22 goes back to the suction of the R. 22 compressor where the cycle is repeated.

A large slow-revving single-stage cargo compressor, withdraws cargo vapour from the cargo tank and discharges it into the Freon-cooled condenser.

The sensible heat and latent heat of condensation of the cargo vapour heats up the cargo condenser, but as soon as this happens the thermostatically controlled expansion valve admits more liquid Freon, which evaporates in the cargo condenser tubes, keeps the condenser cool and, in so doing, removes the heat gained in the reliquifaction process.

To summarise, the Freon system removes heat from the cargo system, and the seawater passing through the R.22 condenser removes this heat into the sea.

The great advantage of the cascade system of reliquifaction, is that the same refrigerant is used for all cargoes, which means that a plant can be designed where the only variable factor is the temperature of the seawater coolant, and because the maximum temperature of the seawater likely to be encountered in service can be easily ascertained, it is not too difficult to design a plant capable of working within these conditions. The plant is usually designed to work with a maximum temperature of the cooling water of 35 deg C. (95 deg F.), and it is very unlikely that warmer cooling water will be met in service.

Additionally, when more advanced types of ships are brought into service to carry products whose critical temperatures are below that of seawater (methane -83 deg C., ethane +32 deg C., and ethylene +9 deg C.), the cascade, or even double cascade, system is the only method available.

When refrigerating cargo, it is usual to refrigerate all tanks simultaneously, but if the condensate were returned to all the tanks, so might receive more than others. Accordingly, it is usual to return all the condensate to one tank at a time for a fixed period and then to change tanks, but allowance must be made for the number of reliquifaction units in service to ensure that equal quantities of condensate are returned, and the tanks not over-filled.

Discharging

Before the discharge commences, the liquid lines on deck must first be cooled down. This can be effected prior to arrival at the discharge berth during the course of refrigeration by returning the cold condensate to the tanks via the liquid line on deck and down through the loading line. (A cross connection between the condensate line and the liquid line is usually provided for this purpose.) However, it should be remembered that because the liquid line is of much larger diameter than the condensate line, the quantity of liquid in the line is very much larger, so the rate of flow is much slower. Due to the extra time spent in the line on deck, the heat gain is greater so, In general, it is more efficient to use the condensate line for refrigerating purposes. The liquid line is only used for condensate return purposes in order to pre-cool that line.

The method of starting the discharge varies slightly with the type of deepwell pump provided. If it is one with a low discharge pressure combined with a booster pump, then the best method to start the discharge is first to flush out any vapour in the liquid line on, deck by using a deepwell pump to transfer a small quantity of liquid from one tank into another, so completely filling, the liquid line on deck with cold product. By shutting the loading valve of the tank into which the cargo is being transferred, the full weight of the deepwell pump discharge pressure is thrown onto the suction of the booster pump. The booster pump can then be quickly purged of any remaining pockets of vapour and, as soon as it is primed with liquid, the booster pump can be started and the liquid cargo sent ashore.

With the more powerful deepwell pumps or submerged, pumps, it is usual to start the discharge by opening the pump discharge valve about a quarter (about two turns) and then start the pump. Many of these powerful pumps need to operate against a back pressure to avoid cavitating, and the discharge valve is regulated to retain the required back pressure on the pump. Additionally, as the current consumption is related to the pumping rate, before opening the manifold discharge valve, it is usual to circulate the cargo by opening the loading valve slightly and closing it as soon as the liquid valve on the cargo manifold is opened and the product discharged sent ashore.

Once the first tank is being discharged, the remainder of the pumps may be started so that all tanks are being discharged simultaneously.

During the discharge, due to the level of liquid in the tanks falling, the vapour spaces become enlarged. If the rate of evaporation of the product within the tank does not keep pace with the rate of discharge, the pressure in the tanks, which is bound to fall anyway, may come close to creating a slight vacuum. In this case, the pressure can be restored by using the ship's vaporiser.

When it is particularly important to discharge the maximum quantity possible (e.g. if the tanks have to be gas-freed subsequent to discharge) the tanks should have the pressure restored prior to draining. The slight degree of undersaturation due to a fall in the tank pressure will cause the cargo pumps to gas-up sooner than would be the case if the pressure were restored.

Towards the end of discharge, when the liquid level in the tanks gets low, the pumping rate must be slowed by shutting in the pump discharge valve, so maintaining the back-pressure. In this way, the tanks can usually be pumped down to a level of about 20 centimetres. The liquid and vapour remaining after discharge is retained on board and used to keep the tanks cold for the next cargo.

Gas-freeing

After ensuring that the condenser is empty of all liquid, the first step is to vaporise the liquid still remaining in the cargo tanks after discharge. This is done by puddle heating. done by puddle heating. To do this, vapour is withdrawn from the top of the tanks by the compressors and discharged into the puddle heat coils at the bottom of the tanks, and therefore immersed in the residual liquid.

The vapour discharged into the coils condenses into a liquid, and the latent heat of condensation warms the surrounding liquid causing it to boil and replace the vapour which has been withdrawn, so that the pressure in the tanks remains fairly constant. Being under the discharge pressure of the compressors, the vapour inside the puddle heat coils condenses readily because, being under pressure, the temperature at which it condenses is much higher than the surrounding liquid. To take a practical example, propane at 3 bars pressure will condense at about – 5 deg C., whereas the temperature of the surrounding liquid propane will be at about – 40 deg C.

The condensed liquid in the puddle heat coils is driven by the pressure from the compressors up the puddle heat return line into the condensate line, where it can be discharged:

(a) into the deck storage tanks, if space is available, for use when gassing-up the tanks on a future occasion;

(b) into another tank, if only one tank is to be gas-freed (e.g. to overhaul a deepwell pump);

(c) over the side, using a flexible hose.

After all the liquid in the tanks has been evaporated, the tanks are warmed by circulating with vapour, using the compressors, sucking from the top of the cargo tanks and discharging, through the gas-heater, if provided, into the bottom of the tanks, thus evaporating any final trace of liquid after puddle heating and warming the tank. It is very important, particularly when gas-freeing with air after an ammonia cargo, to be thorough, and warm the tanks to near ambient. Ammonia has the characteristic of being very persistent, and if the tank-warming operation is curtailed in order to save time and air ventilation started earlier, the whole operation can be ruined.

It is thought that a very thin layer of colder ammonia vapour prevents the warmer vapour from vaporising the liquid. If, say at 0 deg C. it is decided to start ventilating with air, the air breaks through this cold layer of vapour and the residual liquid starts to evaporate and the temperature falls rapidly to an alarmingly low level. Water vapour in the air condenses and forms an dangerous solution with the ammonia and the operation can be prolonged by anything from a week to ten days.

With the cargo tanks warmed to near ambient temperature, the pressure in the tank is reduced to atmospheric pressure by releasing any excess pressure up the mast.

The next stage depends upon the product previously carried. If L.P.G., the vapour must be displaced by inert gas. If the product was ammonia, the ammonia vapour may be displaced by air. In the case of displacing L.P.G. vapour, inert gas is taken from the inert gas generator and forced under pressure into the top of the tank, displacing the heavier L.P.G. vapour from the bottom. The appropriate purge lines will be used, if provided, or the vapour and liquid lines, if they are not. In some ships, it is possible to inert the cargo tanks and displace the L.P.G. vapour in series, the displacing inert gas pushing the L.P.G. vapour from the bottom of one tank into the top of the next. If the ship s lines do not permit this, then the inerting process is done one tank at a time, and sufficient gas introduced into each tank to displace the tank's complete volume. After the tanks have been inerted, the gas-freeing process is completed by flushing through with air until the vessel is completely gas-free

In the case of gas-freeing after ammonia, the inerting process can be omitted, and the tanks flushed through with air but, ammonia-being lighter than air, the air is introduced into the bottom of the cargo tanks, displacing the ammonia through the top. Ventilating with the compressors or blowers is continued until the concentration of ammonia is reduced to an acceptable level (about 700 p.p.m.) when the tank lids are removed and the ventilation supplemented with air-driven fans which, in conjunction with a chute, deliver large quantities of air to the bottom of the tanks, the ammonia vapour welling out through the open hatchway. This greatly increases the rate of dispersal of the final traces of ammonia, the concentration of which should be reduced to below 20 p.p.m. if the next cargo to be loaded is L.P.G.

To Gas-up the Tanks after They have been Gas-freed, Prior to Loading

If the next cargo to be loaded is L.P.G., the tanks must be inerted before the, tanks are gassed-up. The procedure for this is the same as for displacing the propane vapour with inert gas but only 70 per cent. by volume need be passed into each tank. If this method is used, the atmosphere within each tank is thoroughly mixed so that the resulting concentration of oxygen in the tank, is 8 per cent. or below. (It takes a minimum of 10 per cent. of oxygen in air to sustain combustion, and so long as the oxygen content is below this, no combustion can take place.

The inert gas can then be displaced by L.P.G. vapour, the vapour being introduced into the bottom of the tank and the inert gas displaced through the top. Inert gas, being lighter than L.P.G. vapour, will form a layer above the vapour so that there is little admixture of the two.

If the next cargo to be loaded is ammonia, the tanks need not be inerted, but ammonia vapour being lighter than air is introduced at the top of the tank, displacing the air from the bottom.

If deck storage tanks containing sufficient liquid product for the purpose of gassing-up the ship are fitted, there is no problem because the liquid can be vaporised in the ship's vaporiser and directed as required into the cargo tanks whilst the ship is at sea.

If no such tanks are fitted, the process of gassing-up and cooling down must be carried out alongside at the loading terminal. If a vapour return line is provided, vapour (if available) or liquid which can be vaporised in the vaporiser, is taken from shore, and the tanks gassed-up, returning the vapour/ inert gas mixture to the shore where it will be flared. If no vapour return line is provided, then it is quite safe to release the inert gas/vapour mixture up the mast, as is done at sea, but not all terminals will agree to this. If they will not agree, then, one or more tanks can be used as buffer tanks, and one tank gassed up with vapour. The gas/air mixture from the tank being gassed-up is conducted to the bottom of the buffer tank/s where, due to stratification effect, inert gas being lighter than L.P.G. vapour will form a layer above the L.P.G. vapour so that there is very little mixture of the two and practically pure inert gas is released into the atmosphere from the buffer tank. In this way one tank can be completely filled with vapour.

Finally, if the terminal authorities are adamant that nothing may be released to the atmosphere, then the only remaining way is to arrive alongside with the tanks inerted but under no pressure. The smallest tank is then selected for gassing-up, and vapour is taken into this tank so that the pressure rises to a level below the safety valve setting. The inert gas on top of the L.P.G. vapour is then transferred to the other tanks, using the compressors until the pressure in the tank being gassed-up is down to zero. The operation is then repeated, taking more vapour into the first tank and then transferring it to the others. In this way, it is hoped that one tank can be gassed-up sufficiently for the reliquefaction plant to start cooling down and sufficient liquid taken for the ship to proceed to sea and gas-up the remaining tanks.

The procedure for gassing-up with ammonia is the same, except that the ammonia vapour is introduced into the tops of the tanks instead of the bottoms, and the pressure relieved from the bottoms of the tanks.

To Cool Down the Tanks Prior to Loading after Gas-freeing

If the ship's tanks have been gassed-up at sea, there will be no liquid in the tanks. Cooling, down is effected by using the refrigeration process. If the ship is alongside, then liquid can be taken fro in shore and sprayed into the tanks. The liquid droplets sprayed into the tanks will at once vaporise, thus cooling them; but the increase in the amount of vapour in the tanks will cause a rise in the tank pressure. This increase in pressure can be relieved by reliquefaction or by allowing the vapour to return ashore via the vapour return line; but if to do this would involve flaring, such a procedure can be wasteful of product.

In short, the quickest way to cool down is to spray liquid into the tanks and return the excess pressure ashore via the vapour return line. The most economical way (from a conservation of product point of view) is to take sufficient liquid from shore, to maintain a reasonable pressure in the tanks and to relieve excess pressure by reliquefaction, taking extra liquid as the pressures in the tanks fall.

The cooling rate varies from ship to ship, but is usually in the region of 4 deg C. per hour for fully-refrigerated ships.

When the presence of liquid is firmly established in the bottom of the tanks, loading in bulk through the liquid loading line may commence. When the tanks have been cooled at sea by refrigeration after gassing-up, it will still be necessary to spray liquid into the tanks until liquid is firmly established before loading through the main liquid loading line.

SUMMARY OF GAS-FREEING AND GASSING-UP

1. Evaporate all liquid remaining after previous discharge by using puddle heat system.

2. Warm tanks by circulating vapour through gas heater using the compressors.

L.P.G.

3. Displace residual L.P.G. vapour by blowing inert gas into the top of the tank and allowing L.P.G. vapour to escape into the atmosphere from the bottom.

Ammonia

3. Displace residual ammonia vapour by blowing air into the bottom of the tank and allowing the ammonia vapour to escape from the top.

L.P.G.

4. After the tanks have been completely filled with inert gas, ventilate with air.

Ammonia

4. When the concentration of ammonia vapour has fallen to about 700 p.p.m., supplement ventilation with fans and chutes through the tank lids until the concentration is reduced to 20 p. p.m. or below.

TO GAS UP WITH THE VAPOR AS INDICATED

L.P.G.

1. Inert tanks as to reduce oxygen content to below 8 per cent.

2. Introduce L.P.G. vapor into the bottom of the tanks and expel the inert gas through the top.

1. Introduce ammonia vapor into the top of the cargo tanks and expel the from the bottom.

CHAPTER VII: CARGO HANDLING EQUIPMENT

Reliquefaction Systems

In the two types of reliquefaction systems (two-stage and cascade), the deck house in which the machinery is housed is divided into two compartments by a gastight bulkhead (some have a double bulkhead containing an air gap). In the one compartment are located the electric motors, which drive the compressors in other.

The motor room is kept pressurised and is usually provided with two doors forming an air lock for entry. The compressor room (or hazardous area) is kept ventilated but not pressurized.

Two-stage Refrigeration

In the motor room are housed :

(a) the electric motors which drive the compressors;

(b) the electrically driven pump for circulating hot water in the compressor sump-heating system;

(c) any other electrical plant (e.g. air blower driving motor, electrically heated sump-heater tank etc.)

The plant used for two-stage reliquifaction and which is located in the compressor room comprises:

(a) a number of two-stage compressors;

(b) seawater-cooled condensers;

(c) the associated heat exchangers and inter-stage coolers;

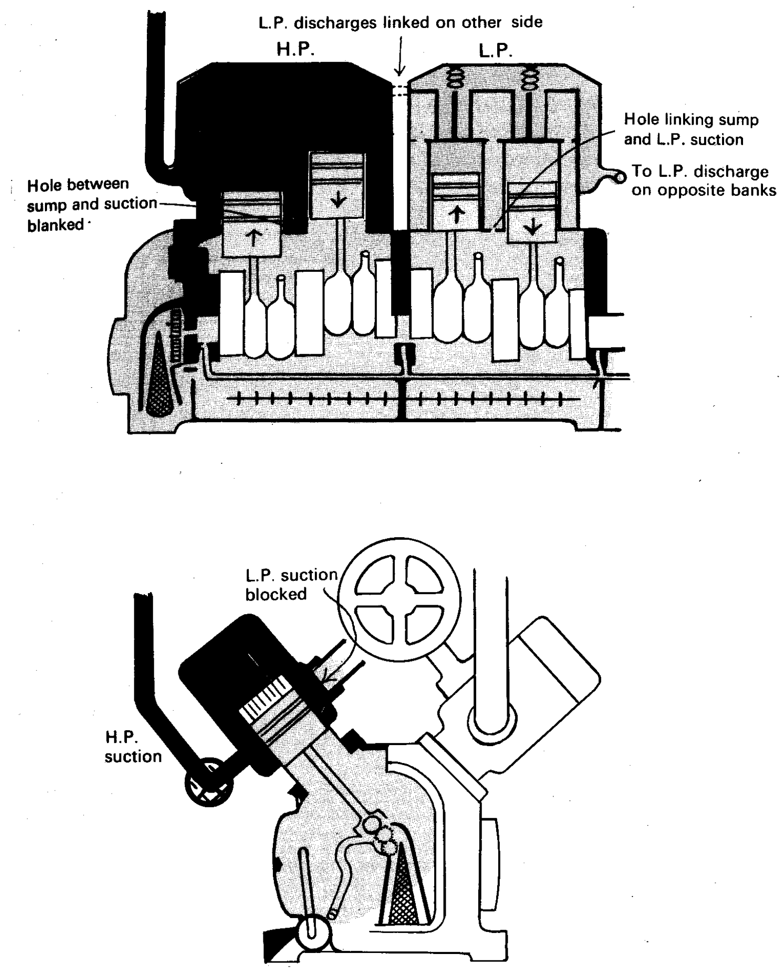
(d) steam-heated tank for sump-heating.

The compressors used for two-stage reliquifaction are generally similar to those used in single-stage, but have been adapted for two-stage operation. They usually have cylinders in multiples of four (3 L.P. supplying I H.P.), i.e. 4, 8 or 12 cylinders.

A typical 8-cylinder two-stage compressor would be generally similar to the Loire compressor described in Part I of this book, having a hollow cylinder block into which the cylinder sleeves are fitted, with suction and delivery plates concentrically arranged, the delivery plates being held in position with strong pins and dished washers.

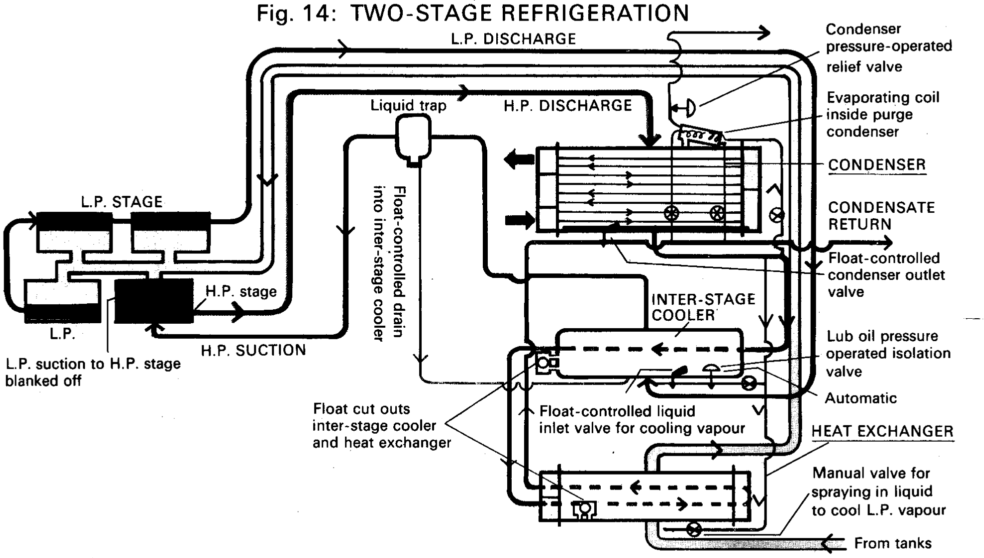
How the compressor is made two-stage is shown by the adaptations to the 8-cylinder Loire compressor. The arrangement of the 8 cylinders is such as to form four separate 2-cylinder compressors, arranged in two banks in "V" formation, so that they are all driven by the same crankshaft. Three of these 2-cylinder compressors are used in the L.P. stage, the fourth in the H.P. stage. Each of these "2-cylinder compressors" has its own suction. The 3 L.P. compressors have their discharge galleries linked together to make a common discharge. The L.P. stage discharges through an inter-stage cooler where the vapour discharged from the L.P. stage is cooled, and is then drawn into the suction of the H.P. stage, which has its own separate discharge. The arrangement is shown schematically in Figs. 13 and 14. Because the suction pipes leading to the L.P. stage have the double function of supplying vapour, and generally speaking bracing the machine, superficially it would appear that the H.P. stage also has an L.P. suction, but this apparent L.P. suction to the H.P. stage is blocked off, and the H.P. unit draws its suction from a smaller inlet pipe.

Fig. 13: Eight-cylinder two-stage compressor
Based on diagrams in Loire Handbook



Lubrication is similar to that of a single-stage compressor, and consists of a gear wheel pump sucking through a conical strainer and discharging through a filter and then a cooler into a distributing pipe which feeds the lubricating oil to the end and centre bearings and shaft seals, the lubricating oil passing through holes drilled in the crankshaft to lubricate the big an little end bearings. The cylinders themselves are splash-lubricated. Lubricating oil pressure is regulated in the same way as with the single-stage compressors by an externally adjustable spring-loaded ball relief valve.

Fig. 14: TWO-STAGE REFRIGERATION



Two-stage refrigeration. L.P. vapour enters heat exchanger at bottom, leaves from top and drawn into L.P. suction. L.P. discharges into inter-stage cooler where it is cooled by liquid from condenser. From inter-stage cooler, cooled vapour is drawn via liquid droplet separator into H.P. suction and then discharged into S.W. cooled condenser.

The compressors are also fitted with a sump-heater to drive off gases which would otherwise dissolve into the oil, thereby contaminating it. The compressor is also fitted with cylinder off-loading devices which off-load 4 cylinders at a time in the proportion 3 L.P. cylinders off-loaded for every I H.P.

The compressors are fitted with the following safety devices:

H.P. cut-out, set at 17 bars;
L.P. cut-out, set at 10 bars;
H.P. and L.P. high temperature cut-cuts, both set at 120 deg C.;
lubricating oil differential pressure cut-out, set at 1-5 bars;
a safety disc cut-out which replaces the older type bursting discs.

Other safety devices not fitted on the compressor itself but on associated equipment are float-operated cut-outs in the heat exchanger and inter-stage coolers to prevent liquid entering the compressors.

Each of the devices listed above stops the machine when actuated. In addition, the machines are fitted with a spring-loaded relief valve in the L.P. suction, operating when the differential pressure between the suction and discharge exceeds 12 bars, which, by connecting the suction to the discharge, causes the compressor to circulate. A similar relief valve in the H.P. suction operates if the differential pressure between suction and discharge exceeds 16 bars. When any of these circulating devices operates, causing the compressor to circulate, the compressor quickly stops itself on a high temperature cut-out.

Seawater Cooled Condensers

The cargo condensers used in two-stage refrigeration are very similar to those used in semi-refrigerated ships, and are fully described on page 15.

The main difference is that an automatic control, sensing condenser pressure, is fitted to the mast relief valve on the incondensible separator. A rise in condenser pressure (which indicates the presence of incondensibles) actuates the controller which causes the mast relief valve to open and release the noncondensibles up the mast to the atmosphere.

Because the normal operating pressure of the condenser varies according to seawater cooling temperature and also with the type of product being reliquefied, the relief setting on the controller can be varied, and is usually pressure of the condenser. set at about I bar above the "normal" operating

The Inter-stage Cooler

In a two-stage compressor, the discharge temperature of the first (L.P.) stage is so high that if the hot vapour were fed directly to the suction of the second (H.P.) stage, the H.P. discharge temperature would be excessive and the compressor would stop itself on the H.P. high temperature cut-out.

Accordingly, the temperature of the L.P. discharge is reduced by spraying in a small quantity of liquid taken from the condenser, which quickly evaporates, uses up latent heat and so cools the vapour before it passes to the H.P. suction. To do this safely, the hot L.P. discharge vapour is fed into the inter-stage cooler. The liquid is sprayed into the L.P. discharge pipe just before it enters the cooler. The liquid injection is controlled by a float which, via a controller, operates a valve permitting sufficient liquid to enter the inter-stage cooler to maintain a low level of liquid. Should the level of the liquid rise due to a failure of the injection control system, a float switch will stop the compressor to prevent liquid entering the suction. The H.P. suction draws vapour from the top of the inter-stage cooler.

A liquid droplet trap is placed between the inter-stage cooler and the compressor H.P. suction to remove any entrained liquid droplets. Should any liquid collect in the trap, it will be drained back into the inter-stage cooler.

Should the compressor stop, the drop in lubricating oil pressure of the compressor operates a controller which closes a valve and shuts off the liquid being injected into the inter-stage cooler, thereby preventing the inter-stage cooler from being flooded with liquid.

The Heat Exchanger

The heat exchanger is situated immediately under the inter-stage cooler. Its main functions are:

(a) to act as a liquid droplet separator (liquid trap);

(b) to exchange sensible heat between the warm condensate coming from the condenser and the cold vapour coming from the tank being refrigerated, so that the condensate is cooled, and the cold vapour warmed and superheated.

The incoming vapour enters the heat exchanger at the bottom, and the compressor draws its vapour from the top of the heat exchanger. It sometimes happens that the incoming vapour is too warm. In that case, it is possible to cool it down by injecting a small quantity of liquid into the vapour line immediately before it enters the heat exchanger. This is done manually and there is no automatic control. The heat exchanger is provided with a gauge glass, and should. any liquid form in the heat exchanger it can be' drained away by a manual cock which drains the liquid into a cargo tank. Should an undue quantity of liquid collect in the heat exchanger unnoticed, a float-operated switch will stop the compressors to prevent liquid being drawn into the first stage of the compressor.

Cascade System of Refrigeration

The motor room, usually called the R.22 room, contains the whole of the Freon system equipment (motors, Freon compressors, Freon condensers and Freon storage tanks), in addition to the motors which drive the cargo compressors.

In detail, the equipment in the R-22 room comprises:

3 single-stage 8-cylinder "V" block compressors;
3 seawater-cooled condensers;
3 R.22 receivers, located underneath the condensers and gravity filled;
3 cargo compressor motors which drive the cargo compressors in the L.P.G. room;
1 freshwater header tank feeding a heater tank;
2 electrically driven circulating pumps used for heating or cooling the crossheads and guides of the cargo compressors. A seawater-cooled heat exchanger is also, fitted for cooling the water returns from the cargo compressor.

The R.22 Compressors

These work in a similar way to the compressors used in semi-refrigerated carriers.

They are usually fitted with oil-pressure operated unloading devices which unload the compressors by holding open the cylinder suction valves so that they can be operated at 25, 50, 75 and 100 per cent. capacity.

The following safety devices are fitted:

Low oil-pressure cut-out (4-2 bars);
High discharge pressure cut-out (17-7 bars);
Low suction pressure cut-out (variable).

R.22 Condensers

These are conventional seawater-cooled condensers with a throughput of seawater capable of condensing R.22 when the seawater temperature is 35 deg C., when its outlet temperature will be about 37 deg C. and the pressure about 15-5 bars.

The R.22 Receivers

These are, located underneath the R.22 condensers and are gravity filled. Each has a capacity of about 0-3 cubic metres and is fitted with a liquid level gauge. They are usually maintained at about half level.

The equipment in the L.P.G. room comprises:

1 filter and liquid trap, in the main vapour line;
3 slow revving single-stage double-acting cargo compressors;
3 Freon (R.22) cooled condensers;
1 methanol injection pump.

Filter and Liquid Trap

This is located where the vapour lines coming from the cargo tanks enter the room from the deck. It is fitted with a float-operated switch which stops the compressors if it is actuated by liquid accumulating in the trap, thus protecting the compressors from liquid entering the compressors.

The Cargo Compressors (See Fig. 15)

In double-acting compressors, both ends of each cylinder are used alternately for suction and discharge. The cylinders are separated from the sump by an entablature with gas-tight glands at the top and bottom through which the piston rod can move up and down when the compressor is running. However, as it is possible for small quantities of gas to leak past the glands, particularly on the compression stroke, the entablature is linked by pipe to the suction end of the compressor, and the sump to the entablature so that any build-up in pressure is avoided.

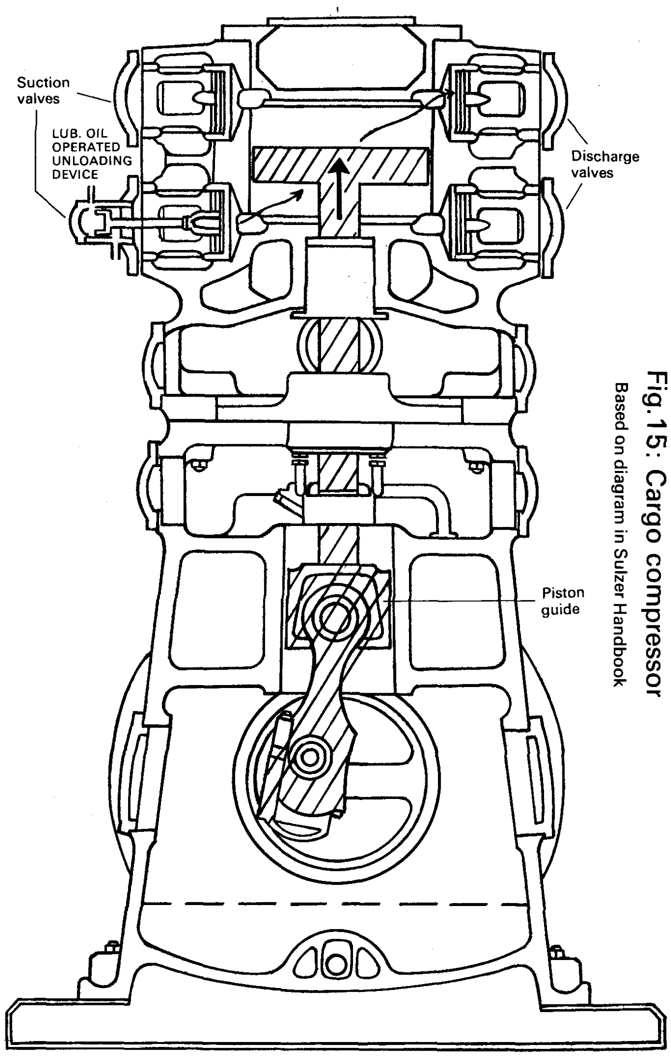


Fig.15: Cargo compressor
Based on diagram in Sulzer Handbook

Lubrication is by means of a gear wheel pump driven by the crankshaft. The pump sucks through a strainer and discharges into the crankshaft where holes drilled in the crankshaft conduct the oil to the main bearings, the bottom end bearings and along the crankshaft to the shaft seal chamber. From the bottom end bearings, the oil passes up through the connecting rod to the top end bearings. The piston guide bearing is splash lubricated. The pistons at the top of the compressor are not lubricated, but have a minute clearance instead, and are therefore oil-free.

Associated with the lubricating oil system are the oil pressure-operated unloading devices, one fitted to each of the two lower suction valves. With this arrangement, the compressors can be run at 50 per cent., 75 per cent. and 100 per cent. capacity. The unloaders work in the following manner. A powerful spring acting on one side of a piston pushes a rod which holds open the suction valve so that on the compression stroke, instead of discharging through the discharge valve, it discharges through the suction valve, thereby unloading the cylinder. By operating a valve on the lubricating oil system, oil pressure acts on the other side of the piston, overcomes the spring, pushes back the piston and allows the suction valve to close, so placing the cylinder on load.

A cooling/heating system is fitted to prevent overheating of the compressor crossheads and guide bearings. The cooling water used for this purpose is freshwater stored in a header tank in the R.22 room, beneath which is a thermostatically controlled heater tank in which the water is maintained at about 50 deg C. The freshwater is circulated by one of two small electric pumps. The hot water returns from the compressor are cooled by a seawater-cooled heat exchanger. The cooled water from the heat exchanger is mixed with the warm water from the heater tank so that the water delivered to the compressor crosshead is at about 35 deg C.

Cylinder jackets filled with anti-freeze mixture absorb the violent temperature changes which take place alternately on the suction (very cold) and compression (very hot) strokes.

The following safety cut-outs are fitted:

low oil pressure (2-8 bars);
low suction pressure (0-8 bars);
high discharge pressure (+ 150 deg C.);
high discharge temperature (5-4 bars);
cooling water high temperature (+ 80 deg C.); and
cooling water low flow (0-6 cubic metres per hour).

The cargo compressors are protected from receiving solids by a strainer located inside the suction pipe, and therefore not readily visible externally.

The Cargo Condensers

The Freon-cooled cargo condenser is a horizontal steel drum through which pass many steel tubes inside which the liquid Freon is evaporated. The end plates are fitted with baffle plates so that the evaporating Freon passes backwards and forwards through the tubes.

The baffle plates are so arranged that the number of tubes through which the Freon passes is a geometric progression. That is, through 3 tubes in the first pass, 9 'in the return,,27 in the third, 81 in the fourth and so on, so that the Freon is being continuously expanded.

Because the volume of Freon passing through the condenser is very much smaller than would be the case if seawater was used as the cooling medium, the end, plates are very much shallower than is the case with a conventional seawater-cooled condenser.

The admission of liquid Freon is controlled by a thermostatically controlled expansion valve located immediately outside the condenser, the sensing bulb for which is in the Freon gas outlet pipe.

The temperature maintained in the condenser varies with the product being refrigerated and is about +3 deg C. for ammonia and about – 6 deg C. for propane, the difference being due to the greater latent heat of condensation for ammonia than propane (301.5 for ammonia compared with 90.4 for propane). The Freon gas return equivalents are about – 5 deg C. for ammonia and about – 15 deg C. for propane.

The condensed liquid outlet from the condenser is controlled by a liquid-level controlled float valve. A hand operated by-pass valve is also fitted. A hydrates trap is situated in the condensate line between the condenser and the liquid outlet valves to prevent hydrates from being returned to the cargo tanks and perhaps blocking up the holes in the spray lines.

On the condenser side of the liquid outlet valve, the condensate will be subject to the same pressure as is maintained in the condenser, but as soon as the condensate passes through the outlet valve, the pressure drops to that of approximately tank pressure. With this drop in pressure, a small quantity of the condensate will boil-off until the temperature of the condensate is reduced to nearly that of tank temperature, so that a mixture of cold liquid and vapour is returned to the cargo tank.

A purge condenser is fitted on top of the main condenser, its function being to separate condensable vapour from incondensible gases, and to release the incondensible gases up the mast to the atmosphere. This is done by leading the very cold condensate line through the purge condenser, thereby cooling it to a much lower temperature than is maintained in the main condenser, whilst remaining under the same pressure.

Incondensible gases such as air and nitrogen are lighter than L.P.G. vapours and therefore tend to collect at the top of the condenser. They pass up into the purge condenser where any L.P.G. vapour content readily condenses and runs back into the main condenser, leaving the incondensible gases behind.

The incondensibles left behind in the purge condenser are automatically released up the mast by a valve which is regulated by a controller which senses condenser pressure and opens the mast release valve whenever the pressure in the condenser rises above a pre-set level.

Methanol Injection System

Propane has the peculiar property of being capable of absorbing more water as a vapour than as a liquid. Therefore, during the process of liquefaction, the water content of the propane vapour tends to separate out from the propane condensate, and the condenser running at sub-zero temperatures would ice up. The most likely spots to suffer from this effect are:

(a) the cargo condensers;

(b) the puddle heat coils.

Methanol is used as an anti-freeze and, if necessary, as a de-icing agent.

To prevent the icing up of the condenser during the process of liquefying the propane, a small electric-driven methanol pump draws methanol from a storage tank and discharges it into the cargo, condensers where the compressor discharge pipe enters the condenser.

The methanol pump is a reciprocating pump running at constant speed, but its output can be varied by altering the length of each stroke of the pump by means of a variable eccentric. The control fitted allows the stroke (output) to be varied. It is usual to set the pump stroke to 15 per cent. at the commencement of refrigeration reducing to about 5 per cent. when the plant settles down.

Vaporisers

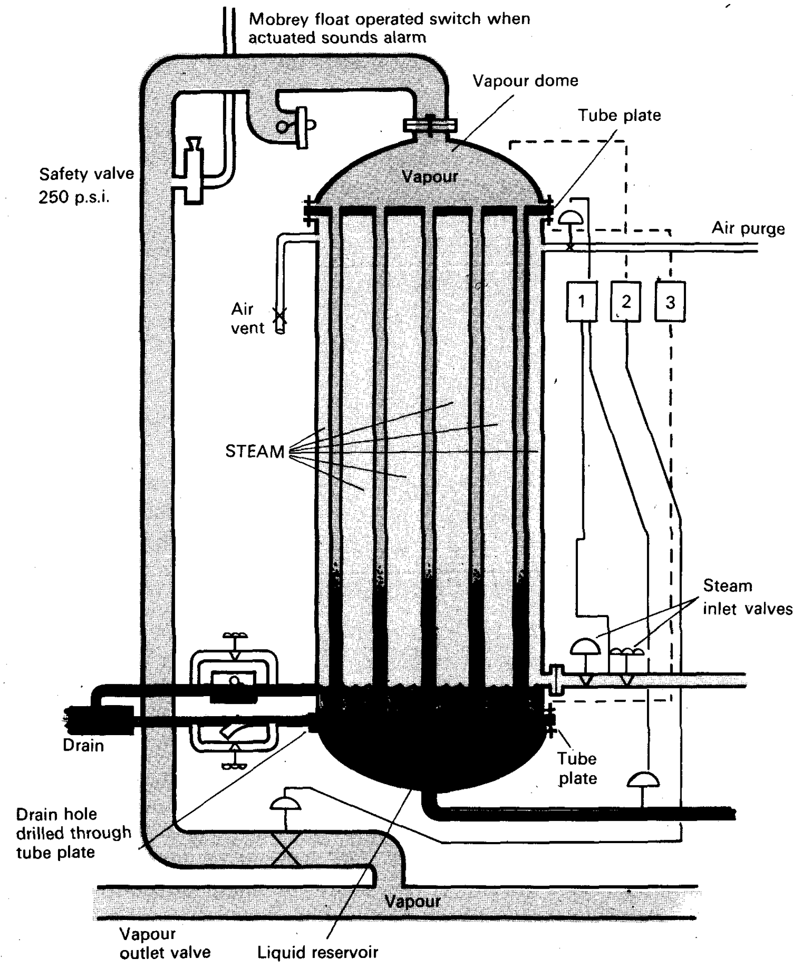
A vaporiser converts a liquid into a vapour with the use of steam heat. There are several types of vaporiser, of which two will be described.

Type "A"

In this type, many steel tubes pass through a steel cylindrical pressure vessel. Bolted to the bottom of the pressure vessel is a dome-shaped cover which acts as a liquid reservoir into which the liquid to be evaporated is admitted. On top of the pressure vessel is mounted a similar shaped dome cover which acts as a vapour space, from which the vapour made in the vaporiser is discharged. See Fig. 16.

Fig. 16: VAPORISER TYPE 'A'

1. Senses steam pressure. Controls liquid admission.
2. Senses vapour pressure in dome. Controls vapour outlet.
3. Indicates liquid level via pressure differential.
1. Also operates air purge if steam pressure falls below 2 bars.



Steam is admitted to the pressure vessel and the steam condensate (water) is drained from the cylinder by two drain lines, one above the other.

The upper drain is controlled by a float-operated valve, draining the bulk of the water during operation, but maintaining a level above the drain line to prevent steam escaping via this outlet. The lower drain valve is thermostatically operated and drains the cylinder completely when vaporising is stopped or suspended so as to avoid the water turning to ice due to the possible presence of very cold liquid in the reservoir and no incoming steam to provide heat which would prevent this from happening. Both drains are provided with manual by-passes.

With the pressure vessel hot and under about 4 bars steam pressure, the liquid to be evaporated is slowly admitted into the liquid reservoir. The reservoir fills and a level established in the tubes inside, the level in the tubes being controlled by the steam pressure controller. Evaporation in the tubes takes place and the vapour so made passes into the vapour space on top of the cylinder whilst the steam condenses into water and is drained away via the drains.

Once working, the automatic control system works in the following manner:

(a) admission of liquid is controlled by the steam pressure controller;

(b) the vapour outlet valve is controlled by the vapour pressure controller.

A liquid level indicator working on the differential pressure between the vapour space and the liquid at the bottom of the liquid reservoir indicates the level of liquid in the vaporiser.

To avoid icing up due to a steam failure, an automatic air purge pressurises the pressure vessel if the steam pressure falls below 2 bars, the air pressure forcing out the steam condensate via the drains.

A safety valve set at 250 p.s.i. is fitted on the dome-shaped cover of the vapour space. A float-operated switch located in the vapour outlet line gives an alarm should the vaporiser completely fill with liquid. A pressure-sensing device shuts off the steam should the vapour pressure in the vaporiser rise above 7 bars.

Type "B"

This type consists of a cylindrical steel pressure vessel into which the liquid to be evaporated is admitted. See Fig. 17.

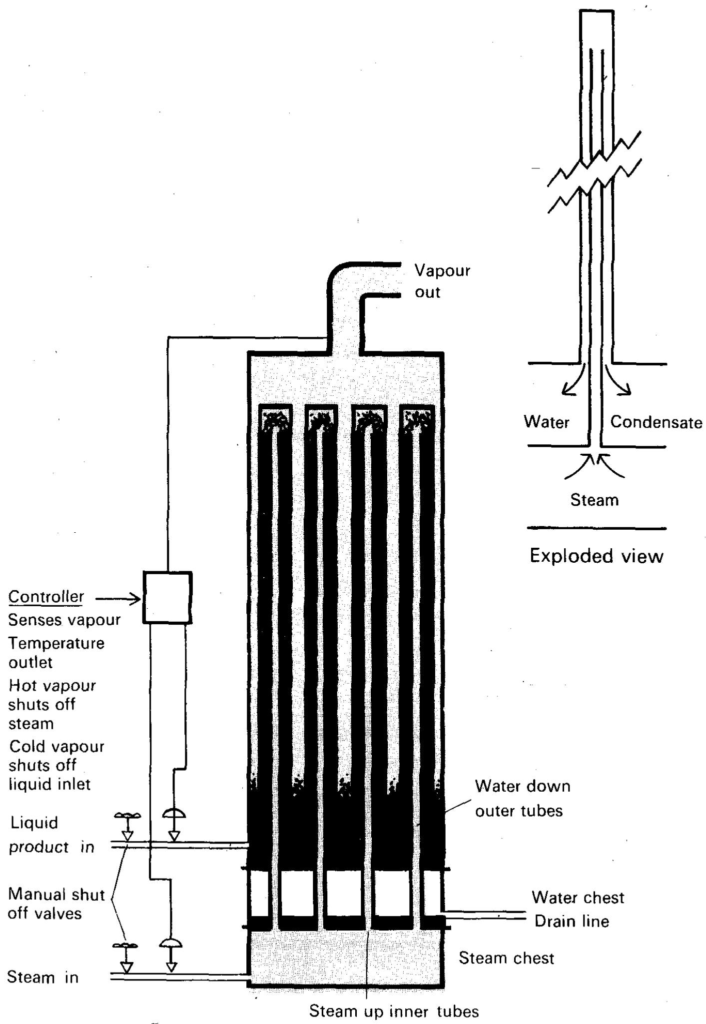


Fig. 17: Vaporiser type 'B'

A large number of double tubes are fitted into the cylinder. Up the inner tube of each pair, steam is fed. The outer tube is blanked and receives the steam, which then condenses and runs down into the condensate compartment above the steam inlet compartment. The condensate is drained from the condensate compartment via a float-controlled drain valve.

Various control systems can be fitted. One of them works in the following way. A vapour outlet temperature-sensing device reduces the admission of steam if the vapour outlet temperature is too high and reduces the admission of liquid if the vapour outlet temperature is too low. These temperature controls are usually set about 10 deg C. apart, that is 5 deg C. either side of the vapour temperature required. They are proportional controls, gradually shutting off the admission of either steam or the liquid to be evaporated, as the vapour outlet temperature departs from its mid-setting so that both the liquid and steam admission . valves are fully open at the mid-position. A condensate temperature-sensing device shuts off liquid admission if the condensate temperature falls below a safe level, so there is no risk of the vaporiser freezing. In this system, the vapour-outlet valve is wide open and there is no vapour-outlet control valve.

The advantage of Type "B" over Type "A" is that it is simpler, produces vapour any required temperature and the condensed water, being over the steam compartment, cannot normally freeze.

Air Dryer

This is used in conjunction with a cargo compressor to reduce the dew-point of the atmosphere in the cargo tanks when they are filled with air after they have been gas-freed and before they have been inerted, by withdrawing air, from the top of the tank. The air is discharged through the dryer and returned to the bottom of the tank. See Fig. 18.

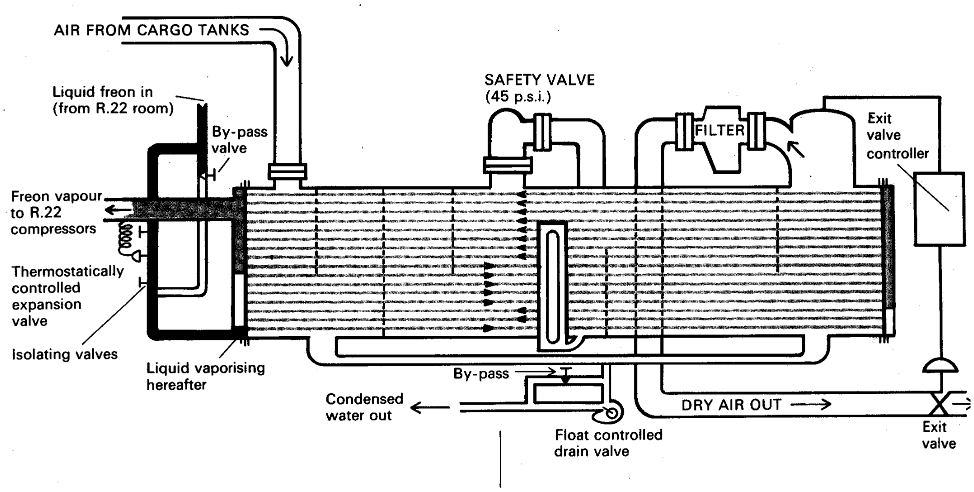


Fig. 18: AIR DRYER

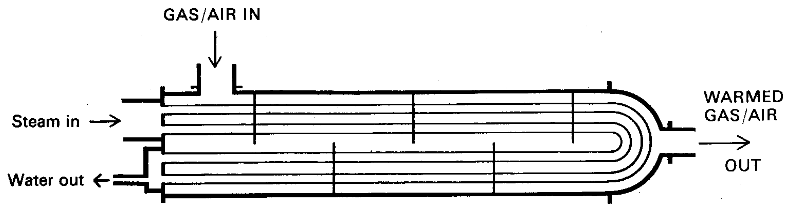
The dryer is Freon-cooled and is similar to a cargo condenser, the liquid Freon evaporating inside the tubes in the dryer. The admission of liquid Freon is controlled by a thermostatically-regulated expansion valve, the sensing bulb of which is in the vapour outlet pipe.

By reducing the temperature of the air passing through the dryer, the water vapour, content is precipitated, the rate and degree of precipitation being increased by maintaining a pressure of 1-8 bars whilst the temperature is reduced to + 2 deg C.

A float-operated valve drains away the condensed water from the bottom of the dryer, the dried air leaving it from the top, passing through a meshed filter. The pressure in the dryer is maintained by a pressure sensitive exit valve.

Gas/Air Heater

This is a simple steam heater consisting of an outer vapour shell and into which steam coils are fitted The vapour space has baffles fitted into it so that the air or gas to be heated zigzags its way through the heater coils as it passes through the heater. See Fig. 19.



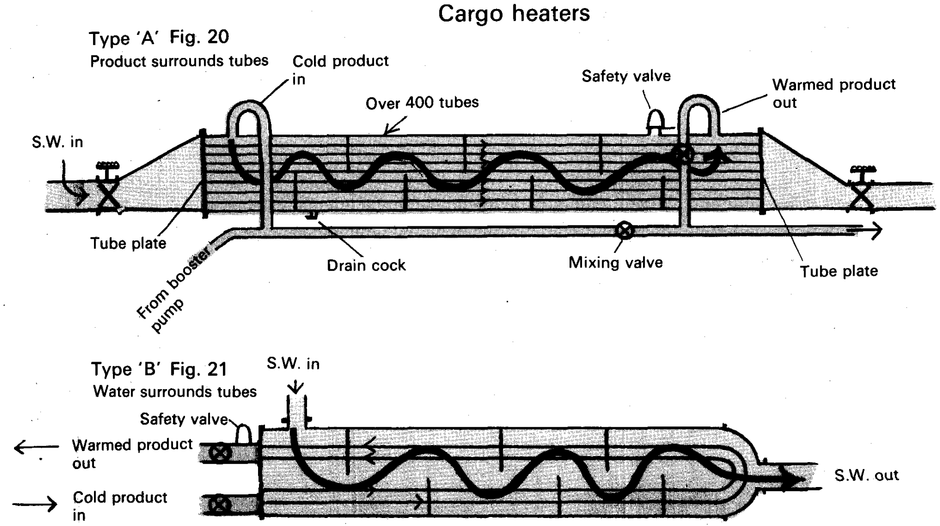
Cargo Heaters

Seawater is used to heat the cargo when it is required to discharge into either ambient temperature or semi-refrigerated shore storage tanks. Two types are described:

Type "A"

Seawater passes through, a large number of tubes inside the heater as the product being warmed zigzags its way through, as shown in Fig. 20.

Cargo heaters



Type "B"

The product passes through a number of tubes in the heater as shown in Fig.21, whilst the seawater zigzags it's way through the heater.

In both types, the heater discharge temperature can be lowered by mixing cold product with the warmed product. The cargo heaters should not be used if the seawater temperature is below 10 deg C. The seawater outlet temperature should not be allowed to fall below 5 deg C. If there is any risk of this happening, the rate of discharge should be slowed down.

Type "B" is considered to be more reliable than Type "A" for the following reasons:

1. If water passing through one or more of the tubes in Type "A" is impeded, there is risk of it freezing and the tube bursting. In Type "B", however, any risk of freezing would be confined to the water in immediate contact with the tubes containing the product.

Ice might form on the outside of these tubes and become an insulating layer. The heater would lose efficiency due to the formation of ice, but it would not cause the tubes containing the product to fracture.

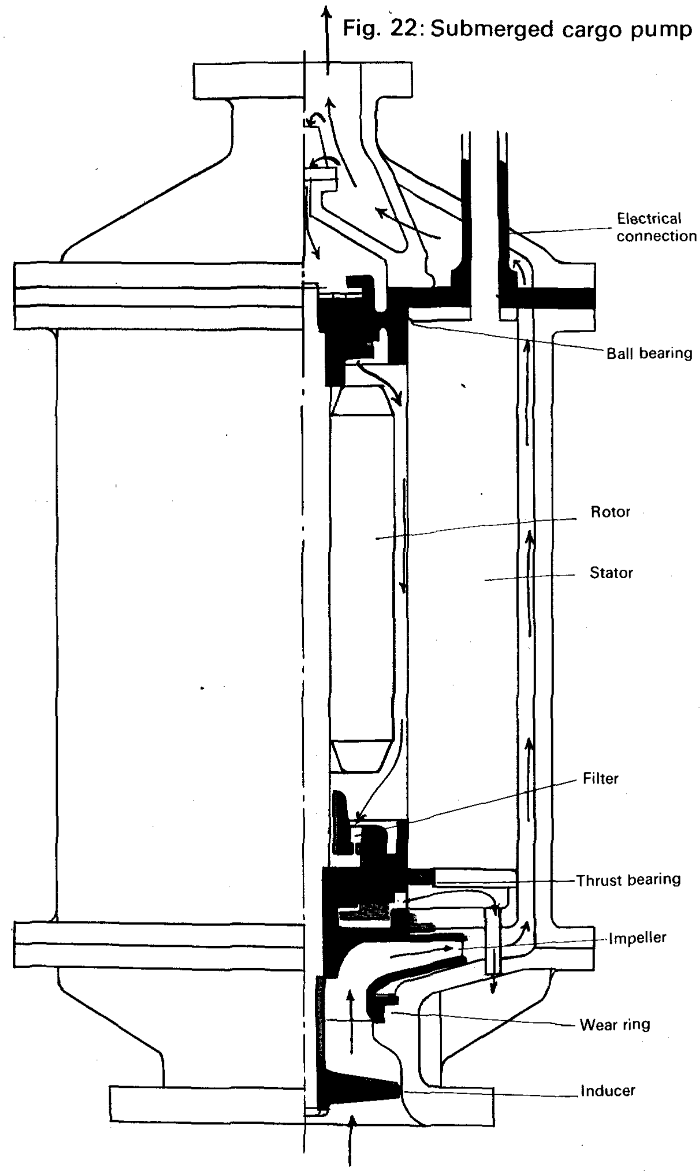
2. The ends of the water tubes in Type "A" are fixed and, not being free to move, any uneven expansion between the tubes and the shell could cause the tubes to be strained or even fractured at the tube plate. In Type "B", the tubes containing the product are free to expand and contract.

Associated with the cargo heater is the Booster Pump. It is used to increase the discharge pressure of the vessel's cargo pumps. It can be mounted on deck provided the motor driving it is adequately flame-proofed. Otherwise, it is located in the L.P.G. room, driven by a motor in the motor room. The pump should be provided with a by-pass so that the cargo heater can be used without it.

Submerged Cargo Pumps

These are centrifugal pumps driven by a 3-phase electric motor, the stator of which is inside a leak-proof container to which the electric supply leads are connected, the stator and drum forming a seated unit. See Fig. 22.

Fig. 22: Submerged cargo pump



The rotor fits inside the stator drum and drives the impeller immediately below, so that the pump and its driving motor are completely submerged inside the cargo tank.

The pumps, as illustrated, suck through the centre. The liquid discharge section forms a jacket around the pump stator and acts as a cooling agent.

The bulk of the discharged liquid is sent up on deck through the pump discharge pipe, but a small proportion of the liquid is fed back to the pump through the top ball bearing, between the rotor and stator, and through the lower ball race to the impeller, thus cooling and lubricating the bearings and rotor. For this reason, it is absolutely essential that the pump is never run without liquid passing through it.

The pump motor is of 200 h.p., is cooled by the liquid discharge and is protected by the following devices:

(a) *Low current cut-out*. This indicates that the pump has lost suction. It stops the pump, and an alarm is sounded.

(b) *High current cut-out*. This indicates (apart from starting up) that the pump is seized or is seizing up, or that the impeller has been jammed by a foreign object. It stops the pump and sounds an alarm.

Though the pump is a centrifugal pump, it has a small axial propeller called an inducer beneath the impeller to assist (or boost) the suction pressure. The pump has a rated capacity of 400 cubic metres per hour against a back pressure of 12 bars.

Electric supply-pump leads. These are well insulated leads, each phase being in a separate stainless steel conduit pipe, sealed at both ends, each conduit pipe being firmly secured and therefore earthed to the cargo pump discharge pipe. The leads pass through a tight gland at the pump end to the motor terminals and terminate on deck in a watertight junction box near the tank entrance. Similar leads connect the junction box to the distribution panel in the engine room. Before using the pump, the whole system should be megger tested and the pump not used if the megger reading is less than 2 megs.

Of such importance is the continuous flow of liquid discharge for cooling and lubricating purposes that the pump must be stopped at once if it does not, pick up suction right away. The starting surge current is so large that it generates a lot of heat and after a pump has failed to pick up suction, it is essential to wait one hour before trying a re-start, so as to give time for the heat generated by the surge current to dissipate. If a pump is stopped after running for some time, it may be re-started immediately because the heat generated in the starting surge current will have been dissipated already.

Emergency Cargo Pump

This is a transferable submerged pump. It is used either to pump out a containment space in the event of either the cargo tank leaking into it or a large quantity of water collecting there, or as a cargo pump in the event of both main cargo pumps failing in a cargo tank.

Emergency pumps are normally rigged in the cargo tanks which, being usually oxygen and water vapour free, would cause less corrosion and damage to the electrical insulation than would be the case if the pumps were kept in the containment space for a long period of time.

The emergency pump is fitted into a trunkway (a tube capable o containing the pump) at the bottom of which is fitted a foot valve which remains shut until the weight of the pump descending upon it causes it to open, so that prior to lowering an emergency pump onto the foot valve, the trunkway should be empty.

The pump is inserted into a tank by removing the trunkway lid on deck and lowering the pump attached to a sectional rod, to which the electric lead is attached. Between each section of the rod is placed a three-legged "spider piece" which centres the rod in the trunkway. The final section of the rod passes through the trunkway lid, and the lid is bolted on the trunkway before the pump's lowered the final few inches onto the foot valve and opening it.

The electric leads are contained in one conduit pipe which passes through the trunkway lid and then secured to the rod by which the pump is raised or lowered.

When the pump is stored in a cargo tank, it is not lowered onto the foot valve but kept suspended above it by inserting a small distance piece between the trunkway lid and a flange at the top of the lifting/lowering rod.

When discharging, the liquid comes up the trunkway, filling it completely, the liquid passing through a discharge valve into a short length of pipe which connects to the main liquid line.

Before transferring an emergency pump, the trunkways affected should be inerted.

Deck Storage Tanks

These are provided for the purpose of storing sufficient liquid product so that the ship may be gassed-up at sea (the cargo tanks filled with the appropriate vapour) so that the ship can cool down her cargo tanks and be ready to load before arriving at the loading terminal. A greater volume of liquid propane is carried because, when vaporised, propane makes a much smaller quantity of vapour than is the case with a similar quantity of ammonia.

For this reason, it is usual to have two liquid propane storage tanks and one of liquid ammonia.

Each deck storage tank is fitted with two safety valves lifting at 210 p.s.i. on the propane tanks and 250 p.s.i. on the ammonia tank. These safety valve settings correspond to the saturated vapour pressure of the products at 45 deg C., which is the highest temperature to which the products are likely to rise in transit.

The tanks are so filled that, after allowance has been made for the products to expand as they warm up, they will occupy 98 per cent. of the space when their temperature reaches 45 deg C., when the S.V.P. of the products will equal the safety valve setting. Any further increase in temperature would result in the safety valves lifting and the vapour escaping, so that the product inside the tank boiled, using up latent heat and so automatically refrigerating itself.

To calculate the percentage to fill the tank at any given temperature, the Specific Gravity of the product at 45 deg C. is divided by its specific gravity at the temperature loaded, and the result multiplied by 0.98.

Each tank is fitted with a vapour line, liquid filling line and, branching from the liquid filling line, a spray cooling line. In each of the liquid filling lines, spray cooling lines and vapour lines excess flow valves are fitted. These excess flow valves are like non-return valves but with a spring holding open the valve lid. When the flow past the valve lid is such as to overcome the tension of the spring which holds it open, the valve shuts. A small hole drilled through the valve allows the pressure on either side of the valve lid to equalize if a valve downstream of the excess flow valve is shut and the excess flow valve opens again. They are fitted to reduce the flow in the event of a hose outside the tank rupturing, thus preventing an uncontrolled emptying of the tank.

To avoid contamination of each other by the two products, the different sets of lines are completely isolated from each other and are blanked off, and have to be connected to the ship's cargo lines by a flexible hose when required.

The tanks are provided with two separate water spray cooling lines.

CHAPTER VIII: CARGO OPERATING PROCEDURE

Loading

Prior to arrival alongside, the vessel's loading lines should be cooled down by refrigeration. Usually the vessel will have reduced her ballast to the extent that safe handling of the vessel will admit.

At sea, to avoid damage, the tank liquid level-indicating floats are raised and secured at the top of the tank. Also, certain pressure gauges in exposed positions, notably on the vapour and liquid cargo manifold, are unshipped and stowed away. On arrival alongside the loading berth, the removable pressure gauges are shipped in position, and the liquid level-indicating floats lowered from their sea-secured position. The normal safety valve springs are supplemented by stronger harbour springs which increase the pressure at which the safety valves operate. The reliquefaction system is usually kept running and the tank pressures should be low (about 0-0.2 bar). After the loading lines have been connected and the tank readings agreed with the shipper's representative, loading may commence.

The tank temperatures may not be quite as they should be on arrival if, due to gas-freeing or changing grades, there is insufficient liquid on board (see p. 51). If so, the tanks, although pre-cooled as far as possible, may need further cooling. This is done by opening the cross connection between the liquid loading line and the condensate line, and receiving product very slowly through the spray lines. The liquid, as it is sprayed into the tanks, will evaporate, use up latent heat and so cool the tank, but at the same time, due to the increase of vapour present in the tank, the vapour pressure will rise.

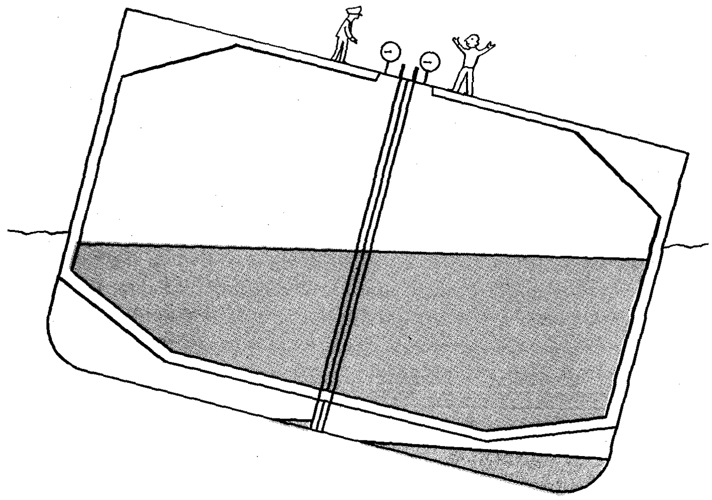
If a shore vapour return line is provided, the excess pressure may be relieved by returning the vapour ashore. Otherwise, it may be relieved by refrigeration, but due to the high pressure set up in the condensate line resulting from the restricting effect of the spray outlets, "spraying in" has to be suspended because the condenser pressure is insufficient to send the condensate back to the tank against the high loading pressure. (Sometimes the liquid can be sprayed into one tank and the condensate sent back to another.)

When the presence of liquid is well established at the bottom of the tank and the tank is cold, loading proper may commence by opening the liquid loading valves and increasing the loading rate.

Whilst loading, although the tanks are cold, the compression of the vapour trapped in the space above the rising liquid level will lead to an increase of vapour pressure. This pressure can be relieved by refrigeration, which is usually better than returning the vapour ashore, because the returned vapour often goes to a flare and is wasted. There may, however, be some good reason, such as the presence of incondensibles or impurities, which override this consideration.

During loading, the vessel has to be further deballasted. Care should be taken to keep the vessel upright at all times, which means keeping the cargo even and the ballast even. Because the sounding pipes are near the ship's centre line, if the vessel develops a list, the slack ballast water will run towards the sounding pipe on the "high side" and away from the sounding pipe on the "low side". This may mislead the officer on watch to assume that there is more ballast on the "high side" than there is on the "low side" when, in fact, the opposite is the case, and he may look for other factors (usually bunkers) to account for the list, The cargo is similarly affected. See Fig. 23.

Fig. 23:



". . . . But Chief, see for yourself, the cargo's even and what little ballast is left is all on the port side. The starboard side is dry."

If the vessel does develop a list during the course of loading, the best way to correct it is to bring the vessel upright with the cargo, adjust the ballast, keeping the vessel upright all the time, and level off the cargo.

The maximum safe loading rate varies from ship to ship but is usually about 500 cubic metres per hour per tank valve open. When loading part cargoes, the loading rate should be reduced accordingly.

During loading, a regular check on all tank soundings must be kept. It is particularly important to keep a check on any tank that has already been filled to ensure that, due to some leaky valve or any other reason, no more liquid enters the tank and so over-fills it.

Completing Loading

High level alarms operated by the tank liquid level indicating device sound at approximately 95 per cent. and 97 per cent. capacity. As each set of tanks is completed, the loading rate is reduced as the loading valves are shut. The vessel is normally loaded to 97 per cent. capacity which corresponds to 98 per cent. when allowance is made for the cargo to expand to the temperature at which its saturated vapour pressure equals the safety valve settings (4 1/4 p.s.i. or 0.3 bar). In practice, this works out as follows:

If by any chance, the shore operators are too slow in shutting off the cargo on completion, the overfill float switches (usually set at 98.5 per cent. capacity and completely independent of the tank liquid level indicating device) operate and shut the loading manifold valve. This is a slow operating valve taking 15 seconds to shut to minimise the surge effects in the shore loading line, the reasoning being that it is better to risk rupturing a loading hose than to rupture a cargo tank. The surge pressure effect is caused by the sudden stopping of the flow of liquid in the loading pipeline. The weight of liquid moving in the shore pipeline acquires considerable kinetic energy and, if suddenly stopped, causes a dramatic surge in pressure. Even 15 seconds is not enough to stop the surge pressure and most modern installations have either a circulating line with a bursting disc or a special surge tank which fills when the bursting disc is ruptured.

The harbour springs should be removed from the safety valves as soon as practicable after loading has been completed and, in any case, before proceeding to sea.

To Refrigerate the Cargo on Passage

In both the two-stage and cascade systems of refrigeration, vapour is withdrawn from the tanks being refrigerated, liquefied and returned to the tanks as a liquid as described on page 43. The technique varies with the type of reliquifaction, plant used.

Two-stage Reliquifaction

Before starting the plant, the flexible couplings on the drive shaft in the motor room and L.P.G. room must have been greased. The grease hardens after a time and the grease should be completely changed periodically (about once a month). The bulkhead seal cooler must be seen to be full of liquid and there must be no blockage in the system.

Further checks are:

(a) that the compressor is turned manually by inserting a bar into the flywheel and rotating it to ensure that the compressor is free to run;

(b) that the oil in the compressor crankcase is at the correct level and temperature;

(c) that water is running through the condenser, and is available for the oil cooler;

(d) that, the oil return valves on the return lines leading from the oil separator traps on both the L.P. and H.P. stages to the compressor crankcase are shut;

(e) that the discharge valves on -the L.P. and H.P. stages of the compressor are open;

(f) that the compressor H.P. suction valve is open and the L.P. suction valve is shut, but free to move; and

(g) that there is no liquid in either the heat exchanger or the inter-stage cooler.

The compressor may then be started. As the L.P. suction pressure falls, the suction valve should be opened slowly, and the rise in oil and vapour discharge pressures carefully watched. The suction valve must be shut and the compressor stopped immediately should the vapour discharge pressure rise abnormally. As liquid forms in the condenser, the inter-stage injection system should be placed in service.

The vapour suction temperature must be carefully watched at the time of starting-up, particularly the L.P. suction temperature which, if unduly high, will so increase the discharge temperature of the L.P. stage as to actuate the L.P. discharge temperature cut-out, causing the compressor to stop.

If necessary, the L.P. vapour suction must be cooled by injecting liquid taken from the condenser into the vapour line just before it enters the heat exchanger. The pipe through which the liquid is injected is of very small diameter and there is little risk of liquid accumulating in the heat exchanger when using this cooling system. The evaporation of the injected liquid uses up latent heat and cools the vapour before it goes to the L.P. stage of the compressor. When the cold vapour from the tank arrives, the liquid injection should be shut off.

The liquid level in the condenser must be watched to ensure that the float-controlled outlet valve is functioning correctly. (Liquid should only show in the bottom of the condenser gauge glass.) The condensate return pressure is checked to ensure that no sprays or filters are impeding the flow back to the tank. In this connection, the filter traps on the condensate line should be cleaned out and filled with methanol prior to loading.

After the compressor has been running some time and the bottoms of the oil separator traps are warm, the return valves on the lines leading from the traps to the compressor crankcase are opened, and the oil heater in the crankcase isolated and the lubricating oil cooler used.

Points to Watch Whilst the Plant is Running

A record should be kept of the plant, covering mainly seawater temperature, condenser pressure, compressor L.P. and H.P. suction/discharge temperatures and pressures, oil pressure, condensate return pressure, etc. Trends are as important as the actual readings.

The state of the compressor cylinder heads should always be under observation. If a cylinder head is unduly cold, this indicates a wet suction; it means that liquid droplets are entering' -the compressor and vaporising during compression, the latent heat of vaporisation re moving the heat which would otherwise be gained in the adiabatic process and is a warning of an excessive quantity of liquid having collected in either the heat exchanger or inter-stage cooler. The compressor must be stopped, the excess liquid drained away and the float cut-out switch checked for malfunction.

If a cylinder head is unduly hot, this indicates a faulty suction valve plate or discharge valve plate,. The compressor should be stopped and the valve plates, checked.

The compressor is stopped by shutting the L.P. suction valve, thus taking the compressor off load, and then stopping the compressor.

As soon as the compressor is stopped, the isolating valves to the interstage cooler and the heat exchanger cooler should be shut to exclude the possibility of these filling with liquid from the condenser during the stoppage.

The lubricating oil heater should be placed in service so that the compressor is ready to start when next required.

During a prolonged stoppage of the compressor, it should be turned daily by hand to distribute the wear on the motor bearings (the steady vibration of the ship causes wear on the ball bearings if kept stationary).

Cascade System of Reliquifaction

In this system there are two sets of compressors and condensers, the Freon or R.22 system and the cargo system, the R.22 system cooling the cargo condenser.

The first step in starting the cascade reliquifaction system is to check that the pumps which provide cooling water for the R.22 condensers are in service, and that power is available for both the R.22 and cargo compressors. The procedure is then as follows:

1. In the R.22 Room, the following checks must be made:

   (a) that the oil levels in the R.22 compressors are correct;

   (b) that the level of Freon in the R.22 receivers is correct;

   (c) that the following valves are shut:

      (i) the compressor suction valve;
      (ii) the oil return valve from the separator trap;
      (iii) the R.22 receiver liquid outlet valve to the expansion valves on the cargo condenser.

   (d) that the following valves are open:

      (i) the R. 22 compressor discharge valve;
      (ii) the valve between the R.22 condenser and the R.22 receiver.

   (e) that the solenoid valve on the same line as the liquid outlet valve is free by running the jack the full length and returning it to its original position;

   (f) that the R.22 compressors are unloaded;

   (g) that the header tank is full on the L.P. G. system in the R.22 room;

   (h) that the L.P.G. circulating pump is running (it is usually left running because, whilst it cools the compressor when the compressor is running, it warms it when it is stopped).

2. In the L.P.G. Room(R.22system)

   (a) that the isolating valves which direct the Freon to the air dryer are shut, and that all isolating valves and by-pass valves on the dryer are shut;

   (b) that the by-pass valves to the thermostatically-controlled expansion valves on the cargo condenser are shut, and the isolating valves on either side of each thermostatically-controlled expansion valve are open.

3. In the L.P.G. room on the cargo side of the system

   (a) that the lubricating oil levels in the cargo compressors are correct;

   (b) that all the fault-indicating lights are extinguished (if illuminated, the appropriate re-set button is pressed);

   (c) that the compressor suction valve is shut and that the compressor discharge valve to the condenser is open;

   (d) that the purge relief valve controller is set to the approximate setting for the product to be refrigerated, i.e. 3 bars for butane, 4 bars for propane and 5 bars for ammonia;

   (e) that the oil-operated unloaders on the compressor are set in the unloaded position;

   (f) that the isolating valves on either side of the float-controlled condenser outlet valve are open; and

   (g) that the purge condenser and tank return valves on the condensate line are shut.

To Start the Compressors

Great care must be taken when starting the R.22 compressors, particularly if the system has been shut down for any length of time and the cargo condensers have become warm. With the cargo condensers warm, the thermostatically-controlled expansion valves through which liquid Freon is admitted to the condenser will be wide open. The solenoid-operated valve on the Freon outlet line opens as soon as the R.22 compressor is started and, unless the manual liquid outlet valve is shut, the initial gush of liquid will fill the condenser before it has had time to evaporate and some liquid may be carried over to the compressor suction. To prevent this, the condenser must first be cooled by manually operating the liquid outlet valve until the temperature of the condenser reaches zero centigrade, when the thermostatically controlled expansion valves will operate automatically.

In the R.22 room, the R.22 compressor low suction cut-out must be turned back to zero. Then the compressor suction valve is cracked open and the compressor started. The oil pressure, suction and discharge pressures must be watched, the compressor being stopped at once if anything is amiss. At first, the suction pressure may be rather high due to liquid Freon having been left in the cargo condenser when the system was shut down on the previous occasion and having subsequently evaporated. The suction pressure should drop quite quickly and, as it falls, the compressor suction valve is opened so as to maintain a pressure of about 3 bars. With the suction liquid outlet valve from the R.22 receiver, pressure at 3 bars, slowly open the adjusting it in such a manner as to maintain this pressure. The R.22 compressor is loaded up to 50 per cent. capacity.

As the temperature in the cargo condenser falls, it is reflected in the vapour suction temperature of the R.22 compressor, and by the time it reaches zero centigrade, the automatic thermostatically-controlled expansion valve should be working and the liquid outlet valve fully opened.

During this start-up period, the temperature of the cylinder heads on the R.22 compressor must be carefully watched as there is always a risk of wet suction. If the cylinder head or heads go cold, the Freon outlet valve must be shut. With a very warm cargo condenser, cooling the condenser can take in excess of half an hour.

With the cargo condenser cold and the automatic expansion valves in operation, the cargo compressor may be started. The compressor suction valve is opened and the compressor started. As soon as the compressor is running satisfactorily, the compressor load is increased to 75 per cent. on the condensate capacity, and the purge condenser and tank return valves line are opened.

The condensation of the cargo vapour inside the cargo condenser gives extra heat, so evaporating more Freon and increasing the pressure on the R.22 compressor suction. The loading of the R.22 compressor should be increased, loading the cylinders one at a time in such a manner that the R.22 suction pressure does not fall below 1.5 bars nor rise above 3 bars. This is continued until both cargo and R.22 compressors are running at full capacity. With both R.22 and cargo compressors running, the R.22 low suction pressure cut-out is re-set to I bar.

The next pair of compressors may be started in like manner. As soon as possible after the plant is running, the methanol injection pump should be placed in service. This is particularly important after the vessel has been gas-freed because of possible increase in the water content due to the absorption of water vapour when the vessel was gassed-up. The stroke of the methanol pump is usually adjusted to about 15 per cent. on starting; after about 2 hours, the stroke is reduced to about 4 per cent.

When the reliquifaction plant has settled down, the purge condenser release valve controller is adjusted from its rough setting to slightly above the condenser pressure.

When refrigerating butane, it is essential to maintain at least 1 bar pressure in the condenser to drive back the condensate to the cargo tanks and the cargo compressor should never be off-loaded to such an extent that the condenser pressure falls below 1 bar or there will be a risk of the condenser priming (filling with liquid).

Points to Watch Whilst the Plant is Running

No condensate must appear in the cargo condenser. If condensate is seen, this indicates that either the condenser pressure is too low, or that a blockage exists in the condensate outlet (probably ice or hydrates). The blockage is usually cleared with methanol.

The temperature of the condensate between the condenser and the float-controlled outlet valve must be checked and if it warms up the compressor should be off-loaded.

If for no apparent reason the suction temperature on the R.22 compressor rises, it indicates that there is insufficient Freon in the system and that the Freon needs replenishment. This rise in temperature is the first noticeable manifestation of a shortage of refrigerant in the system; a noticeable drop in the suction pressure follows.

To replenish the Freon, a bottle of liquid Freon is connected to the valve on the liquid line which supplies the cargo condenser with liquid Freon. The valve on the Freon bottle and the valve to which the Freon bottle is connected and opened and the liquid outlet valve from the R.22 receiver is partly shut so that liquid Freon from the bottle supplements the reduced quantity supplied from the Freon receiver. In this way, Freon from the bottle augments the supply by being evaporated in the cargo condenser and then reliquefied in the R.22 condenser.

To Shut Down the System

The first action is to unload the cargo compressor and then reduce the loading on the R.22 compressor to 50 per cent. The low suction pressure cut-out is wound right back and the liquid outlet valve of the R.22 receiver shut. With the cargo compressor still running, but no more liquid being supplied to the cargo condenser, the liquid already present will be evaporated until eventually the R.22 compressor suction pressure falls and the compressor stops itself on the low suction pressure cut-out. As soon as the R.22 compressor stops, the suction and discharge valves of the compressor are shut.

The cargo compressor is then stopped and the suction and discharge valves shut. The cargo condenser is allowed to empty itself into the cargo tank. Then the condensate valves are shut. Finally, the purge release valve is opened by re-setting the controller to zero pressure so that any trace of liquid cargo remaining in the condenser can evaporate and escape under atmospheric conditions.

Other Points to Watch

Freon is expensive and, to conserve it, all valves on the Freon system are provided with hooded covers and adjustable glands. The glands should be tightened except when it is required to move a valve; and the hoods should be replaced when the valves are not being used. This is particularly important if the R.22 plant is to be shut down for any length of time. When checking the level of Freon in the receiver tank, allowance must be made for the Freon in the cargo condenser when the plant is running.

Discharging

The procedures follow very closely those laid on page 46 (General Operating Principles) to which reference should be made. Prior to arrival alongside at the discharging terminal, the deck liquid lines must be cooled by returning the condensate to the cargo tanks via the deck liquid lines. The cargo pumps should be megger tested and not used if the megger readings are below 2 megs.

On arrival alongside the discharging berth, once the discharge lines have been connected and the tank readings agreed with the receiver's representatives, the discharge may commence. The pump discharge valves are opened about two turns and a loading valve partially opened and the pump started.

The discharge pressure and pump ammeter readings must be carefully watched. If the pump does not show a discharge pressure very quickly, it is an indication that the pump has not picked up suction and the pump should be stopped at once. After the initial starting surge, the ammeter reading should show about 180 amps, but the exact reading should be compared with the consumption graph in the maker's handbook, and the pump stopped if the ammeter reading exceeds 10 per cent. of the rated output. Once started, the pump discharge valve should be regulated so as to maintain a discharge pressure of about 7 - 5 bars on the pump.

Once the product is going ashore, the loading valve must be shut. During the course of the discharge, the tank pressure should be watched and never be allowed to fall below 0.02 bar to exclude the risk of a slight vacuum being created on the tanks. If a shore vapour return line is provided, this should present no problem, but if none is fitted the vaporiser should be started up, drawing liquid from the liquid discharge line and discharging the vapour into the vapour line.

As the level of liquid approaches the bottom of the tank, a careful watch must be kept on the discharge pressure and ammeter readings of the pump. The initial warning of low suction pressure is a fluttering of the discharge pressure and ammeter gauges. The discharge valve must be closed slightly to maintain a steady pressure and, if necessary, the loading valve must be opened slightly to increase the flow of liquid through the pump, thereby increasing the ammeter reading. In this manner, the tanks can be pumped down to a level of about 15 centimetres, when the pump becomes difficult to control and must be stopped (unless it has stopped itself under low current).

In the event of the pump stopping or being stopped during discharge, only one re-start may be attempted. If suction is not picked up right away, no attempt to re-start may be made for one hour in order for the heat generated during the starting surge to dissipate.

When discharging through the cargo heater using the booster pump with a shore back-pressure restriction, control of the booster pump discharge pressure is best regulated by varying the pressure on the booster pump suction, as opposed to partially closing the booster pump discharge valve. The pressure on the booster pump suction is lowered by, circulating part of the liquid discharge by the main cargo pump back into the tank by slightly opening the tank loading valve. This gives far better control.

To Gas-free the Vessel

The main principle underlying safe gas-freeing is to ensure that no air/ L.P.G. vapour mixtures form and, if they do, that they are neither compressed nor heated. After ensuring that the condensers are free of all liquid, the gas freeing operation falls into four distinct phases, namely:

(a) puddle heating;
(b) tank warming;
(c) inerting;
(d) flushing through with air.

Puddle Heating

The first step is to evaporate the residual liquid left behind after completion of the previous discharge. A decision will have to be taken at this stage, whether to save the liquid by transferring it into the deck storage tank, or into another tank if only one tank is to be gas-freed, or to release the product over the side via a flexible hose.

To puddle heat, the lines are set so that the compressors suck vapour puddle heat coils from the tanks to be gas-freed and discharge it into the liquid line and from the liquid (usually via a cross connection into the ship's line into the puddle heat coils, the returns coming up the puddle heat return line into the condensate line for disposal). Then the compressors are started and the puddle heat return valves adjusted to maintain a pressure of about 3 bars in the coils This pressure assists with liquefaction inside the coils because, under this pressure, the vapour will condense at a temperature much higher than that of the surrounding liquid, which is acting as a cooling agent, and so readily condenses. When puddle heating propane, there is a constant risk of the coils icing up. This is because propane can absorb more water as a vapour than it can as a liquid so that some of the water content settle out during-the process of liquefaction and freeze. The principal indications of icing-up in the coils are:

(a) the affected coil return may be less frosted than those unaffected; and

(b) the inlet pressure rises.

If icing-up is suspected, the inlet valve should be closed slowly. If a hissing noise is heard, combined with a rise in inlet pressure, it indicates that that particular coil is clear or has cleared itself. If no hissing noise is heard, the coil is iced up in the tank. When a coil is blocked with ice, the easiest way to clear it is to stop the compressors, insert methanol into the coil, and then re-start the compressors.

During the course of puddle heating, the vapour pressure in the tank tends to rise slowly. When this happens the excess pressure may be reduced, either by releasing the excess pressure up the mast, or by refrigeration (if it is decided to recover the product).

When all the liquid in the tank has been evaporated, the return coils defrost themselves. It is usual to continue puddle heating until no liquid emerges from the puddle heat discharge, as a preliminary to tank warming, is fitted, because the release of latent heat particularly if no gas/air heater due to condensation is the most efficient way to use the compressors, and condensation should take place whilst the tank temperatures are substantially sub-zero.

To Estimate the Time it Will Take for Puddle Heating

The quantity of liquid remaining in the tanks is first calculated. Then, by allowing 1.3 tons for every 1,000 cubic metres passed through the compressors each hour, the hourly air through-put can be calculated. This is then multiplied by the density of the vapour relative to air.

Example:

How long will it take to evaporate 90 tons of (a) propane and (b) ammonia with three compressors each of 1,000 cubic metres per hour capacity?

Compressors hourly through-put of air = 3 x 1.3 = 3.9 tons

(a) For propane: hourly through-put of vapour = 3.9 x 1.5 = 5.85
90 / 5.85 ≈ 16 hours

Therefore time taken will be = about 16 hours

(b) For ammonia: hourly vapour through-put = 3.9 x 0.6 = 2.34 tons
Therefore time taken will be 90 / 2.34 = about 38 hours

It will be seen that ammonia takes considerably longer to puddle-heat than does propane.

Tank Warming

After all the liquid in the tanks has been evaporated by the puddle heat -coils, the tanks are warmed by circulating the vapour using the compressors, drawing vapour from the top of the tanks and returning the vapour through the gas/air heater (if fitted) to the bottom of the tanks. The circulation of the vapour warms up the cargo tanks and evaporates any final trace of liquid remaining after the puddle heating operation. (Traces may be left underneath the puddle heat coils.) The operation is considerably speeded up if a gas/air heater is fitted. It is essential to be thorough with the tank warming operation to avoid any chance of any liquid remaining in the tank because, if any liquid remains, it will evaporate whilst inerting in the next stage, thus completely frustrating that operation, and, in the case of ammonia, the particular problem is explained on page 48, when flushing through with air.

When the tank warming operation has been completed, the method of gas-freeing differs according to whether gas-freeing takes place after an ammonia cargo or after an L.P.G. cargo. After an L.P.G. cargo, it is necessary to inert the cargo tanks. After an ammonia cargo, it is not.

Inerting the Cargo Tanks

In this operation, inert gas supplied from the inert gas generator in the engine room is fed into the top of the cargo tanks via the upper purge line, and the L.P.G. vapour displaced from the bottom of the tanks via the lower purge line and released up the mast. If purge lines are not fitted, the vapour and liquid lines are used instead. Because inert gas is lighter than L.P.G. vapour, it forms a layer over the L.P.G. vapour and there is not much

admixture between the two. It is an advantage if the cargo tanks can be inerted in series (i.e. the inert gas following the L.P.G. vapour from the bottom of one tank to the top of the next until the final tank releases the vapour from the bottom of the tank up the mast, but not all ships have this facility).

Flushing Through with Air

After the tanks have been inerted, the inert gas and any final traces of L.P.G. vapour are flushed through with air, using the compressors (or air blower, if provided), the air following the same path as the inert gas. Flushing through with air continues until the tanks are completely gas-free.

In the case of ammonia, the air, being heavier than ammonia vapour, is fed into the bottom of the tanks and the ammonia vapour displaced from the top, being released up the mast. Flushing through with air should continue until the concentration of ammonia vapour is reduced to about 700 p.p.m., when the tank lids can be opened and the ventilation supplemented by airdriven fans which, by using chutes, deliver more air to the bottoms of the tanks, the ammonia vapour welling out through the tank lids until the ammonia vapour concentration is reduced to below 20 p.p.m. The tanks can then be considered gas-free.

PREPARING THE TANKS TO RECEIVE CARGO AFTER THEY HAVE BEEN GAS-FREED

Drying the Air in the Cargo Tanks

The presence of water, even in the smallest quantities, is always a source of embarrassment to the gas tanker operator because, under operating conditions, it turns to ice. Although the tanks may be superficially dry when the vessel is free of-gas, the water vapour content of the air will condense when the vessel cools down. It is therefore a great advantage to reduce the dew point of the air as low as possible. In the drying operation, air is sucked by the cargo compressors from the top of the cargo tanks and discharged into the dryer, where the air is cooled under pressure and the bulk of the water vapour content condensed and drained away. From the dryer, the air is sent to the gas/air heater, where it is warmed and then returned to the bottom of 'the cargo tank. The dried warm air is so undersaturated as to absorb readily any moisture which has condensed on the tank sides.

To Operate the Air Dryer

The Freon-cooled air dryer uses Freon taken from the system, which normally cools the cargo condensers when the reliquifaction plant is in service, but, being of much smaller capacity, only one R.22 compressor is used, running at 25 per cent. capacity.

The first step is to isolate the cargo condensers and connect the dryer to the R.22 system by shutting all the valves which admit Freon to the cargo compressors and opening all the valves which direct the Freon to the air dryer. On the dryer itself, the valves which isolate the thermostatically controlled expansion valves should be opened, but the valve which by-passes the automatic expansion valve should be shut.

The R.22 compressor is then started and the dryer cooled in the same manner as described on page 62 for cooling a cargo condenser; but in this case, the R.22 compressor is left running at minimum (25 per cent.) capacity.

With the dryer cold, a cargo compressor is started. The dryer outlet valve is adjusted to maintain a pressure of about 1-8 bars in the dryer and, as the plant settles down, more cargo compressors may be brought into service.

Steam is then applied to the gas/air heater and the air in the tanks dried and warmed.

To Inert the Cargo Tanks prior to Gassing-up with L.P.G. Vapour

Inert gas provided by the inert gas generator is fed into the tanks in the same manner as described on page 49. Inerting should continue until the oxygen content in the cargo tank is reduced to below 8 per cent.

To Gas-up the Cargo Tanks

If the vessel is fitted with deck storage tanks, this operation can be carried out at sea, and is rather like gas-freeing in reverse. When preparing the ship to load an L.P.G. cargo, it is usual to gas-up with propane vapour. This is done by taking liquid propane from the ship's deck storage tanks, vaporising it in the vaporiser and sending the vapour so produced into the bottom of the cargo tank to displace the inert gas out through the top, where it is released to the atmosphere.

Before loading ammonia, liquid ammonia is vaporised and the vapour so made fed into the tops of the cargo tanks, displacing the air from the bottoms of the tanks up the mast where it is released.

In both cases, it is a great advantage to use the appropriate purge lines(if fitted) because these distribute the vapour and collect the air or inert gas evenly and so greatly assist the stratification and cut down the degree of admixture due to turbulence. The vapour and liquid lines have to be used if purge lines are not fitted. It is also an advantage if the tanks can be gassed-up in series because this makes better use of the vapour and reduces the presence ,of incondensibles remaining, particularly in all but the very last tank in the series.

If no deck storage tanks are provided, then the operation of gassing-up the cargo tanks must be done alongside the loading berth.

If the shore can provide vapour and a vapour return line, the tanks can be gassed-up by introducing L.P.G. vapour to the bottom of the tanks and returning to the shore inert gas from the top (and vice versa for gassing-up with ammonia).

If the shore can provide a vapour return line but can supply only liquid, then the liquid can be vaporised in the ship's vaporiser and the vessel gassed up, returning the inert gas to shore in the same manner as described above.

To Gas-up the Tanks when no Shore Vapour Return Line is Provided

In this case, a great deal depends upon what procedures the shore authority will agree to. The easiest way is to gas-up the ship in the same manner as is done at sea. Liquid is taken from shore and vaporised. The displaced inert gas-vapour mixture is released up the mast. However, the authority may not agree to this, but it may agree to gassing-up one tank, using one or more other tanks as buffer tanks. This is easy if the ship's line arrangements permit the tanks to be gassed-up in series, otherwise the procedures shown in General Principles on page 50 must be followed.

In this connection, many terminal authorities argue that it is safer to gas-up at sea because, on a calm day, the ship can create its own wind and there is little risk of L.P.G. vapour descending and creating a concentration on and around the ship's decks. Additionally, they do not wish to have any vapour, either L.P.G. or ammonia, drifting round their installations, although it is considered that the concentrations, being minimised by stratification effect and diluted with inert gas, are much weaker than those emitted from crude oil tankers when loading. In fact, for the bulk of the gassing-up period, the concentration of L.P.G. vapour in the inert gas is only in the region of 2 per cent., rising sharply only in the final stages.

Cooling down the Cargo Tanks prior to Loading

If the cargo tanks have been gassed-up at sea, the reliquifaction plant is put into service and the tanks cooled. In this way, the tanks are cooled gently and evenly, but with no liquid in the tanks it may not be possible to reduce the tank temperature to loading level, in which case the final cooling takes place alongside by spraying in liquid.

When cooling down alongside, liquid is taken from shore and, in conjunction with the ship's reliquifaction plant and a shore return line, the pressures created by the evaporation of the liquid taken can be controlled. The tanks are cooled down in the manner described on page 51.

PROCEDURE WHEN CHANGING GRADES AND TYPES OF CARGO

(a) From ammonia to L.P.G.:

Gas-free the tanks, dry the air, inert, gas-up and cool down, so that the vessel is ready to load. Particular care must be taken to reduce the ammonia content to below 20 p.p.m. when gas-freeing and, when loading in the Persian Gulf area, to below 5 p.p.m. In this connection, it is probable that the concentration of ammonia in the cargo tanks will be further reduced during the gassing-up process.

(b) From L.P.G. to ammonia:

Gas-free the tanks, dry the air and then gas-up with ammonia vapour .and cool down. If gassing-up has to be carried out alongside, and the loading authority insist that the tanks be inerted prior to gassing-up, pure nitrogen must be used and not inert gas from the inert gas generator because the carbon dioxide content and other impurities present in the gas supplied from this source will form carbonates.

(c) To change grades between the following products:

Butane, butene, butadiene, propane, propene.

It is sufficient to puddle heat the liquid out of the tanks and then cool down. Because butene (butylene), propene (propylene) and butadiene are unsaturated hydrocarbons, they require an oxygen-free tank. For this reason, one should never gas-free the tanks prior to loading them (unless following an ammonia cargo), when the tanks must be inerted to reduce the oxygen content to below 2 per cent. in the case of propene and butene and 0-2 per cent. in the case of butadiene.

PART III

GENERAL

CHAPTER IX: CARGO CALCULATIONS

The main difference between making cargo calculations for a conventional tanker and for a gas tanker is that in the conventional tanker only the liquid product loaded or discharged is calculated. Thus, a tank empty of all liquid is regarded as empty. In a liquefied gas tanker, however, because the liquid the quantity of vapour remaining product is easily converted into a vapour on board after discharge (or converted into a liquid during loading) must be taken into account, in addition to the liquid loaded or discharged, when making the cargo calculations

Because the cargo tanks of practically all liquefied gas tankers are calibrated in cubic metres, this will be assumed to be the case in the examples which follow. If the cargo tanks are calibrated in units other than cubic metres, the principles of calculation remain the same, but the necessary conversion factors will have to be used. The procedure for making the calculations is as follows.

Prior to loading, the shore terminal should provide the vessel with the density at 15 deg C. of the product to be loaded. In this connection, it is extremely rare for a vessel to load a pure product (except in the case of ammonia). Commercial propane usually contains small proportions of other hydrocarbons, butane, ethane, etc., which have the effect of slightly altering the density of the product (and with butane, also). On completion of loading, the terminal authority usually provides the vessel with a chemical analysis of the product loaded.

To ascertain the quantity loaded, the small quantity of product on board prior to loading (heel plus weight of vapour) is subtracted from the total quantity of product on board after loading. In the I case of ascertaining the quantity of cargo discharged, the quantity of product remaining on board after discharge is subtracted from the total quantity of product on board prior to discharge.

Making the Calculations

After the tank readings (tank pressure, liquid and vapour temperatures and the tank soundings-depths of liquid) have been agreed with the shore representatives, various adjustments have to be made before the volume occupied by the product can be correctly assessed. The adjustments are:

(a) Trim correction to the soundings as read, to make allowance for the fact that, in most cases, the tank liquid level indicating devices are not centrally located. This trim correction, when applied, gives the corrected sounding.

(b) With the corrected sounding, the volume of liquid is read from the tank calibration tables and, by subtracting it from the total volume of the tank, the vapour volume can be ascertained.

(c) Because the tank will have contracted if the tank temperature is below 15 deg C., the volumes obtained from the calibration tables have to be multiplied by the shrinkage factor for the temperature concerned to give the corrected volume of the spaces occupied by the liquid and the vapour.

(d) Low-sounding trim corrections are also tabulated to allow for the wedge shaped volume when the liquid level touches the forward end of the tank bottom.

To Calculate the Quantity of Liquid on Board (Metric)

Two methods can be used. The most direct method is to convert the density of the liquid at 15 deg C. to its density at loading temperature and then to multiply the density at loading temperature by the corrected volume occupied by the liquid. The result will be in metric tons. To convert the density of the liquid at 15 deg C. to its density at loading temperature, one can either consult the Density Reduction to 15 deg C. Table (ASTM-IP Table 53) and obtain the density at loading temperature directly or, by consulting the Volume Reduction to 15 deg C. (ASTM-IP Table 54), obtain the factor for the product at the loading temperature and then multiply the density at 15 deg C. by the factor so obtained. Both methods should give the same answer.

Example:	Density of product at 15 deg C.:	0.509 kilogrammes per litre
	Temperature of product on board:	-39 deg C.
	Sounding as read:	12 metres 32 cms.

Trim correction:	7 cms.
Corrected sounding	12 metres 25 cms.
Liquid Volume:	4567.890 cbm
Shrinkage factor -39 deg C.	0.9988
Corrected Volume	4562.409 cbm

(1) Density of product at −39 deg C. obtained directly from Table 53=0.579 kilogrammes per litre.

(2) Volume Reduction factor for product at −39 deg C. obtained from Table 54 is 1.137:509 x 1.137 = 0.578733

(3) Corrected Volume 4562.409 x 0.579 = 2641.348 metric tons
4562.409 x 0.578733 = 2640.417 metric tons

The second method is to adjust the corrected volume occupied by the liquid at the loading temperature so that it is equivalent to the volume it would occupy if the liquid were allowed to warm up and expand to 15 deg C. This is done by multiplying the corrected volume by the coefficient of expansion for the temperature concerned, as shown in the Volume Reduction to 15 deg C. Table (ASTM-IP Table 54). The volume occupied at 15 deg C. is then multiplied by the density at 15 deg C. to give the quantity in metric tons. Working the same example shown above, commencing at the corrected Volume, we get:

Corrected Volume	4562.409 cbm
Volume reduction Factor	1.137
Volume at 15 deg C.	5187.459 cbm

Volume at 15' C. 5187.459 x 0.509 = 2640.417 metric tons

Both methods I give the same result (or very nearly so) because the same factor (Volume Reduction) can be used either to obtain the density at loading temperature or to obtain the volume the liquid would occupy at 15 deg C. In other words, the three factors used are the same, namely, volume at loading temperature, Volume Reduction Factor and density at 15 deg C.

The second method is preferred to the first for the following reasons:

(a) Product is frequently sold by the litre and 15 deg C. is a more practical temperature for the distributor than, say, - 40 deg C.

(b) A table of Volume Reduction Factors will cover a fairly wide range of densities, whereas to list each density separately with the same degree of accuracy requires a much larger set of tables. Due to the restriction of the number of decimal places given in the density reduction table, small arithmetical differences arise.

To Calculate the Weight of Vapour on Board (Metric and Imperial)

The vapour calculation is quite simple and the formula is based on the following laws:

(a) *Gay Lussac's Law*: The density of a gas at standard temperature and pressure is proportional to its molecular weight.

(b) *Charles's Law*: The volume of given mass of gas is directly proportional to the absolute temperature, provided the pressure remains the same. If the formula is transposed, it can be deduced that the density of a given mass of gas varies inversely with the absolute temperature provided the pressure remains constant.

(c) *Boyle's Law*: The volume of a given mass of gas is inversely proportional to its pressure, provided the temperature remains constant (or density varies with the absolute pressure, provided the temperature remains constant).

(d) 1/22400 is half the density of hydrogen (H_2) which gives the theoretical density of 1 cubic metre of H (as opposed to H_2)-the simplest and lightest atom. (See section relating to molecular weights.)

Written for a fixed temperature, the individual effects of these laws are:

Gay Lussac's Law = Density varies with molecular weight of the vapour.

Charles's Law = Density varies inversely with absolute temperature.

Boyle's Law = Density varies with absolute pressure.

1/22400 =A constant.

The conclusions derived from the three laws can be combined to give formula for Vapour Wt. as:

$$Volume \times absolute\_pressure \times \frac{273}{273+t} \times molecular\_Wt \times \frac{1}{22400}$$

Assessing the volume occupied by the vapour.

The vapour volume is obtained by

(a) subtracting the volume of liquid in each tank from the total volume of each tank;

(b) the separate vapour volumes of each tank are then, multiplied by the shrinkage factor to give the corrected vapour volume for each tank;

(c) the corrected vapour volumes for each tank are then added together to give the total corrected vapour volume.

The total corrected vapour volume is then used with the mean pressure and temperature to make the vapour calculation.

Example :
What is the weight of 29.952 cbm of propane vapour at 0.1 bars gauge pressure at -30 deg C ?

0.1 bars gauge pressure = 1.1 bars pressure absolute
-30 deg C = 243 absolute temperature
Molecular weight pf propane = 44 (See Table at the end of Chapter)

$$Weight = 29952 \times 1.1 \times \frac{273}{243} \times \frac{44}{22400} = 72.708MT$$

Another method is to calculate the weight of air corresponding to the pressure and volume required and then:

$$Weight\_of\_vapour = Weight\_of\_air \times \frac{Molecular\_weight\_of\_vapour}{Molecular\_weight\_of\_air}$$

Because air is roughly a mixture of 80 per cent. nitrogen and 20 per cent. oxygen and

Molecular weight of Nitrogen (N_2) = 28
Molecular weight of Oxygen (O_2) = 32

$$\begin{cases} The\_Nitrogen/Oxygen\_mixture \\ equal\_to\_air\_has\_average \\ miolecular\_weight\_of\_29 \end{cases}$$

Taking air as having a density of 0.001293 metric tons per cubic metre at 0 deg C, using the formula provided by Charles's Law,

$$A_t = \frac{273}{273+t} \times 0{,}001293$$

a table of densities for each degree centigrade can be compiled. Re-working the same example given above, using the short method, we get :

$$29952 \times 1.1 \times 0.001453 (density\_of\_air\_at\_-30\_\deg\_C) \times \frac{44}{29} = 72.634MT$$

The answers are not exactly the same, but they are sufficiently close to bear comparison.

To Calculate the Quantity of Liquid on Board (Imperial)

The method used is basically the same as that for metric system except the barrels or cubic feet are used for measurement of volume and temperature is measured using the Fahrenheit scale, and the Specific Gravity at 60 deg F, is given instead of density.

The steps are :

(a) converting the corrected volume in cbm to barrels (or cubic feet);

(b) using the volume reduction to 60 deg F. factor (ASTM-IP Table 24), converting the volume in barrels into that which the liquid would occupy at 60 deg F., giving *net barrels*;

(c) consulting the table which gives long tons per barrel for various Specific Gravities (ASTM-IP Table 29), obtaining the required factor and multiplying the net barrels by this factor. The answer will be in English long tons.

To Calculate the Correct Volume of Liquid to Load when Loading a Full Cargo

The maximum volume of cargo that may be loaded into a cargo tank is governed by the relief pressure setting on the cargo tank safety valves. The rule is that no more cargo should be taken than that which would occupy 98 per cent. of the cargo space after allowance has been made for the cargo to expand to a temperature, the saturated vapour pressure of which would lift the safety valve. In effect, this means that if for any reason it is not possible to refrigerate the cargo, the cargo will expand as it warms up and, at the same time, its vapour pressure will rise, until at a certain temperature, the increase in vapour pressure will cause the safety valves to open and the excess pressure relieved up the mast. The release of the excess pressure will cause the product inside the tank to boil, use up latent heat and, in this manner, the cargo to refrigerate itself so that it will not get any warmer.

The ship must be so loaded that when the temperature/pressure of the cargo corresponds to the safety valve relief setting, the cargo occupies 98 per cent. of the cargo space.

The calculation is made in the following stages:
(a) From a table or graph, ascertain the temperature at which the saturated vapour pressure of the product corresponds with the relief setting of the safety valve.

(b) Ascertain the density (or specific gravity) of the product at:

    (i) the temperature at which the saturated vapour pressure of the product corresponds with the safety valve setting,
    (ii) the density (or specific gravity) of the product at the loading temperature.

(c) Dividing the density at "lift-off" temperature by the density of the product at loading temperature and multiplying by 98 gives the percentage of the volume which can be loaded.

(d) Multiply the percentage so obtained by the total volume of the tank and this will give the maximum volume that can be loaded in that tank.

From the calibration tables, the sounding corresponding to this volume can be ascertained.

Semi-refrigerated and Pressure Ships

The coefficient of expansion for liquid gases is very high and in semi-refrigerated ships the allowance for expansion can be very high. Where the rise in saturated vapour pressure due to temperature increase is such as to be unlikely to equal the safety valve setting (e.g. butane), the cargo tanks are so filled that the tank are 98 per cent. full when the cargo temperature reaches 45 deg C., the highest temperature likely to be reached in service.

Vessels capable of carrying both semi-refrigerated cargoes and fully refrigerated cargoes at atmospheric pressure usually have the facility of being able to alter their safety relief valve settings from about 1-7 bars when carrying semi-refrigerated cargoes to about 6.3 bars when carrying semi-refrigerated cargoes by the superimposition of stronger springs on the safety valves.

In pressure ships which do not refrigerate their cargoes, all cargoes are so loaded as to occupy 98 per cent. of the cargo tank volume when the temperature reaches 45 deg C. In practice this usually works out at about 85 to 90 per cent. of the cargo tank capacity at normal temperatures, but the exact percentage of the volume to fill must always be worked out.

Expansion Relief Valves on Liquid Pipelines

Due to the high coefficient of expansion of the products carried, all liquid lines capable of isolation (i.e. those sections of liquid lines between shut-off valves) are provided with safety relief valves to prevent the lines concerned splitting due to the "hydraulic effect" occasioned by expansion of the liquid inside the pipeline.

In this connection, the ship's pipelines are usually rated ASA - 150 or ASA - 300, the figures 150 and 300 relating to the safe working pressure of 150 p.s.i. and 300 p.s.i. respectively. The manifold connections are such that an ASA-150 connection will not fit an ASA - 300 connection without the use of a special adaptor, so that those responsible for the conduct of cargo operations are made aware of the pressure restriction and can be careful not to overstress the pipelines.

To Calculate the Correct Volume to Load when Taking a Part Cargo

In this case, allowance must be made for the weight of the vapour displaced by the liquid loaded.

The calculation is made in the following way:

(a) Divide the metric tons to be loaded by the density of the product at the loading temperature. The result will be approximately the volume in cubic metres of liquid to load.

(b) Ascertain the weight of vapour displaced by the liquid (weight of vapour of the volume obtained in (a), above) and increase the original quantity of liquid to load by this amount.

To Calculate the S.V.P. of a Mixture of Products at a Given Temperature

It is sometimes necessary to work this out when carrying mixtures of products. The calculation is made in four stages, namely:

1. Divide the component *weights* of the mixture by their respective molecular weights.

2. Add the results together and then divide each individual result by the sum of all the results. This gives the *mol fraction*.

3. Multiply the S.V.P. of each product at the temperature concerned by its mol fraction. This gives the *partial pressure* exerted by each product.

4. Add the partial pressures and, by Dalton's Law of Partial Pressures, the sum of the partial pressures is the total absolute saturated vapour pressure exerted by the mixture.

Example:

What is the S.V.P. of a mixture of 10 tons of propane and 10 tons of butane at +10 deg C.?

S.V.P. Propane at +l0 deg C. = 6.32 Bars absolute: Molecular Wt.=44
S.V.P. Butane at +10 deg C. = 1.49 Bars absolute: Molecular Wt.=58

1.

$$\left.\begin{array}{l} \text{Propane}\dfrac{10}{44} = 0.2273 \\ \text{Butane}\dfrac{10}{58} = 0.1724 \end{array}\right\} \quad \text{TOTAL } 0.3997$$

2.

$$\left.\begin{array}{l} \text{Propane}\dfrac{0.2273}{0.3997} = 0.5687 \\ \text{Butane}\dfrac{0.1724}{0.3997} = 0.4313 \end{array}\right\} \quad \text{TOTAL } 1.00$$

3. Partial pressure exerted by propane = 0.5687 x 6.32 = 3.59
   Partial pressure exerted by butane = 0.4314 x 1.49 = 0.64

4. Total S.V.P. of mixture = 4.23 bars absolute or 3.23 bars gauge.

To Calculate the Individual Proportions of Vapour in the Vapour above a Liquid Mixture

To do this, the total pressure above the mixture should be divided by the partial pressures exerted by each product and the results will be the individual proportions of vapour in the vapour above the mixture.

In the example given above, the individual proportions are:

$$\text{Propane}\frac{3.59}{4.23} = 0.85\_or\_85\_per\_cent.$$

$$\text{Butane}\frac{0.64}{4.23} = 0.15\_or\_15\_per\_cent.$$

NOTE: Mixtures are usually by volume, not by weight, in which case the respective weights constituting the mixture must be determined before making the above calculations.

Molecular Weights

Because frequent reference is made to molecular weights, a brief reference to them and how they are determined is given below.

The molecular weight of a molecule is the sum of the atomic weights of the elemental atoms which comprise the molecule. In this connection, a molecule consists of at least two atoms, so elemental molecules consist of two elemental atoms. Thus, the chemical formula for hydrogen is written H_2, oxygen 0_2, nitrogen N_2, etc. Some useful atomic weights are listed below.

Hydrogen	=	1
Carbon	=	12
Nitrogen	=	14
Oxygen	=	16
Chlorine	=	35

NOTE: These figures are not exactly correct because the weight of the electrons has been disregarded, but they are very nearly correct and are sufficiently accurate for our purpose. The chemical formulae of most of the products carried are listed below, together with their molecular weights.

Saturated Hydro-carbons

Methane	CH_4	16
Ethane	C_2H_6	30
Propane	C_3H_8	44
Butane	C_4H_{10}	58

Unsaturated Hydro-carbons

Ethylene	C_2H_4
Propylene	C_3H_6
Butylene	C_4H_8

Non hydrocarbon products carried in liquid gas vessels include:

Ammonia	NH_3	17
Vinyl Chloride	CH_2 CH Cl	62

Aid to Memorizing the Formulae

The names of the saturated hydrocarbons end in "ane". They are stable compounds and have no tendency to change their state, and are normally burnt as fuel. In the order above (which is the order of their respective atmospheric boiling temperatures), methane has one carbon atom, ethane 2, propane 3, etc. If the number of carbon atoms is doubled and 2 added, that is the number of hydrogen atoms in the saturated product.

The unsaturated products have the same number of carbon atoms as their saturated equivalents, but two hydrogen atoms have been removed from the molecule, so that ethane becomes ethylene, propane becomes propylene, butane becomes butylene. The removal of two hydrogen atoms makes the molecules comprising the product chemically unstable. The molecules tend to link up with one another to form very long molecules, particularly in the presence of oxygen, forming polymers. The process of forming polymers is called polymerisation. This must be avoided, so unsaturated products are loaded into an oxygen-free environment.

Butadiene is a doubly unsaturated product with 4 hydrogen atoms removed from the butane molecule. It is even more chemically unstable than butylene and, in the case of butadiene, an inhibitor is added to retard further the polymerisation process.

ISO-butane is an isotope of butane where the shape of the butane molecule has been altered, giving iso-butane somewhat different thermodynamic properties from those of butane, which is sometimes called normal butane, or n-butane.

Comparison of Metric and Imperial Systems

Fundamental differences exist between the two systems and an understanding of these differences is necessary when comparing the results of the two. The metric system is an absolute system, completely decimalised. The system is described as absolute because the weights are "in vacuo" weights (as weighed in a vacuum), whereas under the imperial system, the weights are "in air" weights, so that when comparing the weights, allowance has to be made for the weight of air displaced.

In the metric system, water has a density of 1 gramme per cubic centimetre at 40 deg C. (39 deg F.), when it is at its most dense. At 15 deg C., its density would be somewhat less. For this reason, because weights of cargoes are calculated for a temperature of 15 deg C. and not 4 deg C., specific gravities are not used but the density of the product at 15 deg C. used instead, so preserving the decimal virtues of the metric system.

Under the imperial system, the unit of weight is the pound and the unit of volume the gallon, which is that amount of space occupied by 10 pounds of water at 62 deg F. when weighed in air. The complication does not end there because, in the oil industry, specific gravities are given at 60/60 deg F. (i.e. the density of the product at 60 deg F. compared with the density of water at 60 deg F.). At 60 deg F., water weighs very slightly more than 10 pounds per gallon and somewhat less than 1 gramme per cubic centimetre. For converting density at 15 deg C. to S.G. 60/60 deg F., ASTM-IP Table 51 should be consulted (and vice versa)

In order to compare the results obtained by the two systems, metric tons are converted to metric tons in air by using the factors provided in ASTM-IP Table 56. The metric tons can then be converted into long tons by multiplying by the factor 0.98421.

When making vapour calculations, the imperial system neglects the "in air" factor and makes use of the same method of calculation as does the metric system.

The foregoing explanation is given because discrepancies sometimes arise due solely to the different methods of calculation, combined with neglecting to use the factors mentioned above, particularly when trading between a country using the metric system and one using the imperial.

Other Points to be Borne in Mind

When carrying fully refrigerated cargoes, some receivers require very low "on arrival" tank pressures. If mercurial "U" tubes are used as tank pressure measuring devices, they are affected by fluctuations in the atmospheric pressure, whilst the pressures in the tank are absolute. Thus, a pressure of 0.04 bars at 1010 millibars atmospheric pressure will show 0.02 bars at 1030 millibars and 0.06 at 990 millibars.

If the cargo contains a relatively high ethane content, some loss in transit and difficulties with reliquifaction can be expected. Thus, a 2 per cent. by weight ethane content dissolved into the cargo will create about 18 per cent. ethane content in the vapour space.

PROPERTIES OF PRODUCTS CARRIED

PRODUCT	Chemical Formula	Mol. Weight	TEMPERATURE °C. Boiling[2]	Critical	Ignition	Flash Point	Flammable Range%	Density Boiling Temp.	Density Liquid 15° C.	S.V.P. 15° C. (Bars)[3]
Methane	CH_4	16	−161	−82·5	+595	Very Low	5−15	0·425	Gas	Gas
Ethane	C_2H_6	30	−89	+32	+515	−125	3−13	0·542	0·374	33·8
Propane	C_3H_8	44	−43	+97	+460	−105	2−11	0·582	0·508	7·3
Butane	C_4H_{10}	58	−0·5	+152	+410	−60	1·8−8·5	0·600	0·584	1·8
Ethene[1]	C_2H_4	28	−104	+9	+425	Very Low	2·7−29	0·575	Gas	Gas
Propene[1]	C_3H_6	42	−48	+91	+497	−108	2−11	0·613	0·522	8·9
Butene[1]	C_4H_8	56	−6	+147	—	—	—	0·623	0·601	—
Butadiene	C_4H_6	54	−4	+152	+450	−60	2−11½	0·651	0·628	2·0
Iso-Butane	C_4H_{10}	58	−12	+134	—	—	—	0·594	0·563	—
Ammonia	NH_3	17	−33	+132	+651	Indefinite	15−26	0·631	0·6175	7·3
Vinyl Chloride	$CH_2CH\ Cl$	62	−15	+142	+472	−78	4−22	0·972	0·950	3·0

NOTES

[1] Ethene, Propene and Butene are alternative names for *Ethylene, Propylene* and *Butylene*, respectively.

[2] Boiling temperatures are given for atmospheric pressure.

[3] S.V.P.s listed are absolute pressures.

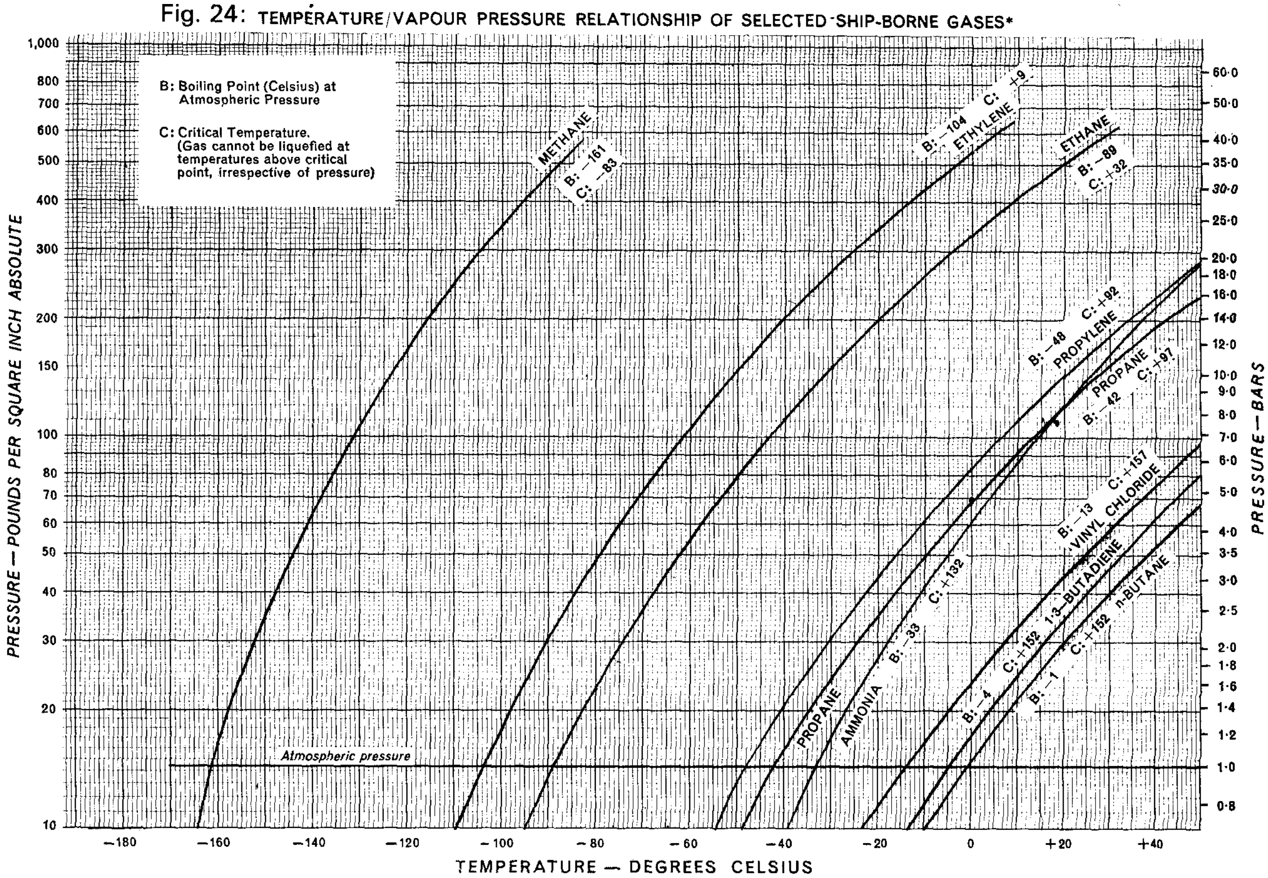
SOME USEFUL DATA

Standard (sea level) atmospheric pressure = 29·92 inches mercury, which is equivalent to 760 millimetres, or 1013·2 millibars. In vapour calculations, it is accepted practice to regard 1 bar (1000 millibars) as 1 atmosphere, but this is not strictly correct.

Factors for converting: Metric tons (in air) to long tons = 0·98421
Long tons to metric tons = 1·01605
Cubic metres to barrels = 6·2898

Density of air at standard atmospheric pressure and at 0° C. = 0·001293 metric tons per cubic metre. Long tons NIL.

Fig. 24: TEMPERATURE/VAPOUR PRESSURE RELATIONSHIP OF SELECTED SHIP-BORNE GASES*



* Curves constructed by application of Antoine equation, using data from "Selected Values of Properties of Hydrocarbons and Related Compounds", American Petroleum Institute Research Project 44, Thermodynamics Research Centre, Texas A. & M. University, and from "Advances in Chemistry Series: No. 22" (1959) published by the American Chemical Society.

The two main safety hazards are those of fire and the avoidance of entering oxygen-deficient spaces.

Fire, however caused, represents the biggest hazard to a liquefied gas tanker. It is best examined from three distinct aspects:

1. fire prevention;
2. fire detection, so that in the event of a fire breaking out, it can be tackled in its early stages;
3. firefighting.

PREVENTION

This involves three main considerations:

1. collision avoidance (safe navigation);
2. safepractice;
3. efficient detection of gas concentration before it reaches a flammable mixture.

Safe Navigation

The principal risk of collision will always lie in the long river or canal transits to the gas terminals, but those responsible for the navigation of the vessel can ensure that the transits are only made under favourable conditions,

namely:

(a) good visibility (at least 1 mile), and

(b) the steering capability and engine reliability are perfect.

One of the biggest risks is the possible loss of all electric power (blackout). In consultation with the Chief Engineer, the electrical load and the supply available should be adjusted to reduce this risk to an absolute minimum.

(It was an electrical supply failure that caused the *Esso Maracaibo* to collide with the Maracaibo bridge, causing it to collapse, resulting in considerable loss of life and extremely extensive damage.) In shallow water transits, where the vessel is required to make the transit at even keel, a reliable trim indicator must be provided and consulted to ensure that the steering qualities of the .ship are not adversely affected by the vessel trimming by the head due to shallow water effect.

Although the personnel of a gas tanker may take all the necessary responsibility of keeping it in good order and ensuring that adequate supplies navigational precautions, there is nothing they can do with regard to the operation of other vessels making the transit at the same time.

Safe Practice

This covers the correct handling of the products and ensuring that all the safety devices of the cargo handling machinery operate efficiently. For this reason, they should be regularly tested. Gas-freeing must be suspended when lightning is in the vicinity.

Additionally, a constant watch must be kept for any leaky joints or glands and these repaired as soon as found. The most vulnerable spot for corrosion is the condensate line, which is the most used line. The cold product causes water vapour in the air in contact with the exposed portions of the line to condense and form frost or dew, which in time causes rusting. In practice, it has been found that the most likely danger points are where the insulation ends and a few inches back under the insulation. The pipes always rust from the outside inwards and, almost without exception, never internally. Pipes covered by saturated insulation are always suspected.

Gas Detection

This is of vital importance because it gives warning of a potential fire risk before the risk has reached dangerous proportions, in time for remedial action to be taken. The gas detector continuously monitors all spaces adjacent to the cargo, both in storage and handling, the most important being containment spaces, compressor room, motor room and instrument spaces.

The detector is fitted in a cabinet from which sample lines lead to the various spaces to be tested, each sample line terminating in what amounts to a large valve chest in the gas detector. Each valve is held closed by a spring and opened by a solenoid when the line is being used for sampling. In the event of a concentration of gas reaching 30 per cent. of the explosive level, an alarm is sounded, and a light indicates the space affected.

There are two basic types of gas detectors, one operating on the principle of the heat of combustion varying the value of a resistance on a Wheatstone bridge, so putting it out of balance and causing a current to flow across the bridge, measured by the percentage indicating device. The other type acts on the principle of Infrared absorption. The Infrared type of gas detector is being used in increasing numbers.

It is of vital importance that the detector should never be switched off and be kept running efficiently. An officer should be given the personal responsibility of keeping it in good order and ensuring that adequate supplies of span and zero gas are held on board for calibration purposes and that regular adjustments and calibrations are carried out in accordance with the manufacturer's recommendations.

DETECTION

Fire Detection

Early fire detection is of the greatest importance so that a fire can be tackled in its early stages and before it gets a firm hold.

Most gas tankers are comprehensively fitted with fire detectors, which are of 3 basic types:

(a) heat sensors;
(b) combustion (smoke) detectors;
(c) flame detectors.

Heat detectors are the simplest type and are fitted in all accommodation and store spaces. They are actuated by the rise in temperature occasioned by fire.

Combustion detectors are fitted in all machinery spaces and compressor and motor rooms. They work on the principle that a fire emits particles of matter into the atmosphere. The majority are invisible to the naked eye, the remainder can be seen as smoke. The combustion detectors are sensitive to those particles invisible to the naked eye.

Flame detectors are fitted in the engine room. These detectors are sensitive to infra-red heat radiated from flames and are responsive to flame flickering.

Because this form of detection can be masked by smoke; both types of detectors (flame and combustion) are fitted.

When any of these detectors are actuated, they sound a distinctive alarm and the location of the fire is indicated on a panel (or panels) suitably located.

FIGHTING

Fire-fighting

Most operators of L.P.G. tankers, being seamen, are familiar with the procedure of combating fires in the accommodation and engine room, so this section is confined to fighting L.P.G. fires.

Experiments ashore have shown that the most effective way of fighting L.P.G. fires is to shut off the supply at source and extinguish the fire by starvation rather than by attempting to extinguish it by other means. This is because, if the fire were to be extinguished without stopping the supply of inflammable vapour, there is a very real risk of a cloud of vapour forming and suddenly re-igniting.

The main safety device is the emergency shut-down system which, when operated, shuts all valves in the cargo system and also shuts off the electrical current to the cargo handling equipment. The emergency shut-down system has fusible plugs incorporated in it, which, when heated (as by a fire), melt and operate the emergency shut-down system automatically.

Two sorts of L.P.G. fires can be envisaged. The one due to ignition of an escape of liquid and/or vapour whilst the cargo system is intact, the other caused by a collision, when a cargo tank is ruptured.

In the first case, control of the emission of liquid or vapour can normally be established and the fire fought in accordance with the principles laid down, which is to shut off the source of supply of fuel and allow the fire to burn itself out, at the same time carrying out what amounts to extensive boundary cooling to prevent the fire from spreading. This involves turning on the bridge front sprays and, if possible, so to manoeuvre the ship that the flames blow clear.

Since a pool of L.P.G. liquid will vaporise and burn all in one place, it should be possible for men wearing fire-proof suits approaching from upwind to work close to the fire, particularly if others further off keep them soaked with water. In this way a valve which may have failed to close automatically may be shut.

The effect of the fire may be to warm up the cargo in the other tanks, causing the safety valves to lift and add more fuel to the fire, so, in addition to cooling the area covered by the flames, all the tank domes and pipelines of the unaffected, tanks must be cooled by solid jets of water. If any of the water turns to steam, that area requires additional cooling.

Flames from safety valves should never be extinguished; they are sufficiently far removed from a cargo tank as not to heat it. The vapour released should be allowed to burn itself out.

In the case of a fire, resulting from a collision where a tank has been ruptured, there is no possible means of controlling the escape of fuel so as to extinguish the fire by starvation. The best chance of survival is to remove the ship from the area of spillage by going astern and bringing the stern up-wind so that the flames are blown clear over the bows. Control of the ship moving astern can be maintained by short bursts of speed ahead. It is useless to put the wind on the beam so that the flames are blown clear, because the leeway will cause the ship to drift into the middle of the pool of evaporating and burning liquid.

However, never is the advice "prevention is better than cure" more true than in relation to fire on board liquid gas vessels.

OXYGEN-DEFICIENCY

Precautions to be Taken when Entering Spaces which May Have a Deficiency of Oxygen

The most likely spaces to have a deficiency of oxygen are spaces which were previously inerted and which may have been inadequately ventilated and ballast tanks . which have been empty for some time in which rusting has taken place .

To understand the dangers of entering these spaces, a description of the effects of oxygen-deficiency and carbon dioxide excess is given.

Air consists basically of 79 per cent. nitrogen and 21 per cent. oxygen. Oxygen is the life-sustaining component and nitrogen acts as a dilutant. When breathing, part of the oxygen content is turned into carbon dioxide, whilst the nitrogen content remains unchanged.

Carbon dioxide stimulates the breathing; too much over stimulates it, causing the individual to pant and in excessive quantities (over 10 per cent.) it is a poison and kills.

in normal circumstances (e.g. an unventilated room), as oxygen is used up, it is replaced by carbon dioxide and eventually those inside will "gasp for air" and be uncomfortable, but it is the over stimulation of the breathing due to an excess of carbon dioxide being present that causes the discomfort, not the lack of oxygen. If the carbon dioxide content of the atmosphere were removed, all signs of discomfort would disappear, but all inside would suffer from a lack of oxygen

It is the complete lack of discomfort experienced with oxygen-deficiency that is the biggest danger. Oxygen-deficiency affects first the brain, causing the victim to become, in turn, befuddled, stupid and sleepy, eventually to die if the oxygen content falls below 10 per cent.

This information is provided to warn operators of the special dangers to be met when entering the spaces referred to and of the very thorough ventilation required. In the case of ballast tanks, these should be completely filled with water and then emptied before entry.

In the case of containment spaces, ventilation must be thorough and prolonged. Those working in the containment space must have a ventilation chute of the concertina type (elephant's trunk) with them, air being supplied by an air-driven fan on deck close to where they are working.

When in spaces adjacent to inerted containment spaces, (e.g. in a double bottom under a containment space), the pressure in the inerted space should be reduced to zero to exclude the possibility of inert gas leaking into the double bottom tank.

Rescue breathing apparatus should be placed at the entrance to the tank or containment space, with a man to maintain contact with the working party, usually by portable radio.

CHAPTER XI: RECOMMENDATIONS

This section is controversial and is intended to promote thought and discussion. Its object is to point out directions along which improvements can be made without waiting for recommendations following a post mortem after a disaster has taken place.

Safe Navigation

Operators of liquified gas tankers must be among the most safety-conscious seamen in the world. First and foremost, collision is considered to be by far the greatest hazard. The effects of a collision causing the rupture of a cargo tank would be extremely serious, but fortunately such an event has not yet occurred, not even in the collision between the *Yuyo Maru* and *Pacific Ares.*

It is possible, however, to visualise the effects. If a tank of 10,000 cubic metres were ruptured, approximately 6,000 tons of propane would be affected. That proportion which spilled into the sea would vaporise very quickly, but although the bulk of the vapour cloud so formed would be over-rich and not burn, that part of it in contact with air and not over-rich would almost certainly be ignited by the sparks and heat generated by the collision and burn around the edges with great intensity, drawing in more air to sustain combustion. The heat of this combustion, combined with the heating effect of any water that entered the ruptured tank, would cause the remainder of the product left inside the tank to vaporise so that practically all 6,000 tons would be burnt. In short, it would be equivalent to a multi-thousand bomber raid in World War II. It is quite likely that other of the ship's cargo tanks would be affected, magnifying the effect.

That is the hazard to be avoided, and it really is not much use hoping that it will never happen. Some positive preventing action is needed.

In the long term, it would be a great advantage if long river or canal transits were reduced by placing gas terminals near the mouth of a river in areas of low population density. This would reduce the risk of collision by shortening the confined water transit and reduce the possible disastrous environmental effects of a collision should one take place.

Harbour Control

A great deal can be done to increase safety through harbour control. The United States and Japanese governments have given the world a lead in laying down rules for safe navigation when using their ports. The rules are tailored to suit individual ports, but cover:

(a) Minimum visibility for making the entry. Under Japanese regulations, entering and leaving must be carried out in daylight only in good visibility. U.S. regulations restrict the movement of loaded vessels to daylight in good visibility. Empty vessels may move at night, provided the visibility is adequate.

(b) Provision of escort which proceeds ahead of the liquified gas tanker to enforce traffic regulations.

(c) In some cases the movement o other ships is restricted by harbour control services whilst a gas tanker is moving.

Additionally, the U.S. and Japanese governments inspect gas tankers to satisfy themselves that the ships are in efficient working order and well maintained. In fact, a U.S. Coastguard Certificate of Compliance (with their requirements) has come to be regarded by many authorities outside the U.S. as a guarantee of efficiency.

Enforcement of Traffic Separation Systems

Although international traffic separation systems have been in existence for some time, little has been done beyond moral persuasion to enforce them. Such a lax situation would never be tolerated on the roads and, by way of a start, wilful breaking of traffic separation rules should void the insurance, in the same way as an unjustified deviation does.

Emergency Isolation Valves for Safety Valves

These should be fitted because, although the safety valves on liquified gas carriers are generally very reliable, they have occasionally operated below their correct pressure settings and also failed to re-seat properly after having operated.

There is a hazard if, due to a malfunction of a safety valve, large quantities of L.P. G. or ammonia vapour are released unnecessarily into the atmosphere, with no means of stopping the release.

The isolation valves would be linked together so that only one of a pair of safety valves could be isolated at any one time, leaving the other safety valve still in service. Under operating conditions, both isolating valves would be in the open position so that both safety valves are in service.

If a nitrogen line were fitted between the isolation and safety valves, an additional facility would be provided for the regular testing of each safety valve. Without an isolation valve, the only practicable means of testing and adjusting the safety valves is to pressurise the whole cargo tank. As the ship is rarely gas-free, this involves the release of a substantial quantity of vapour into the atmosphere and this can only be done at sea. It is very difficult and expensive to arrange for the "Classification Society" surveyors to supervise the operation and then put their seal on the tested valves.

When a liquid gas tanker arrives in port, particularly a loading port, the harbour heads, which increase the relief setting of the safety valves, should be fitted to prevent the undesirable release of vapour when the cargo tanks are being cooled by the process of the evaporation of liquid product whilst it is being sprayed into the tanks., If, however, surveyors' seals have been placed on the safety valves, these harbour heads cannot be fitted without disturbing the seals. Were isolation valves fitted, these would permit the testing of the safety valves before the cargo operation commenced and could then be sealed in the open position.

Although superficially increasing the relief pressure setting of the safety valves may appear to increase the risk of straining the cargo tank by over-pressurising it, this is not the case. The cargo tanks being empty, without the weight of liquid in them, no extra strain is involved except at the top of the tank. A ship which has a normal safety relief setting of 0.3 bar must work close to this setting in order to cool down. Increasing the relief setting to 0.4 bar does not imply that the operators would increase the pressure in the tank to this level. They would still work to the normal pressures, but if the pressure inadvertently increased, say, to 0.32 bar, no vapour would be released.

The environment would be much protected because the risk of vapour release is reduced.

The settings of the safety valves may alter slightly during the course of a year, but the fitting of isolation valves would overcome this difficulty by permitting tests, adjustments and, if necessary, repairs to the valves to be made at frequent intervals and so provide greater security than annual tests and surveyors seals.

Greater consultation between Operators and Design Staff

There must be greater liaison between those who operate the ships and those who design them. The main areas of bad design relate to:

(a) Unsuitable valves. Frequently it would appear that little thought is given to the function of a valve and the type of valve provided to fulfil a particular function.

(b) Inefficient lay-out of piping systems.

(c) Bad lay-out of monitoring equipment.'

Operators are in a good position to give advice because their experience covers ships designed by a great number of firms in different countries, and having, operated the ships, are-in a position to appreciate the good points for inclusion in future construction.

Finally, seamen should be consulted before drastic changes are made. The replacement of hydraulic steering control by electrical control is a good example. Hydraulic control enables a quartermaster to steer the ship without having constantly to watch the helm indicator, because he knows when the wheel is amidships and that a spoke or two either way enables him to steer the ship.

This is not so with the usual form of electrical control, the rudder moving when a contact is made and stopping when the contact is broken. To bring the rudder back to amidships, the contact must be made in the opposite direction and stopped when the rudder indicates amidships. This means that the quartermaster must continuously refer to the helm indicator and take his eyes .off the compass or steering mark to do so. No motor manufacturer who wished to provide his vehicles with power-assisted steering would be allowed to market such a system.

Electrical control is ideal for automatic steering when the ship is at sea, but requires considerable skill to operate manually and with the ship being steered automatically at sea, many seamen get little practice in its use. The views of pilots would be very valuable in this regard.

GLOSSARY OF TERMS USED

BOILING: This is the action which takes place when a liquid changes its state from a liquid into a gas or vapour. The heat required to bring this change of state about is called Latent Heat.

BOILING TEMPERATURE: This is the temperature at which a liquid boils. As the boiling temperature rises with an increase in pressure (see saturated vapour pressure), the boiling temperatures are usually given for atmospheric pressure. At this pressure, water boils at + 100 deg C., butane at –1/2 deg C., ammonia at –30 deg C. and propane at –43 deg C.

CONDENSATION: This is evaporation in reverse. If a vapour becomes supersaturated, condensation takes place and heat is surrendered. For example, in a seawater cooled condenser, a compressor has raised the pressure it of the vapour to such an extent that at seawater temperature, is supersaturated. Condensation takes place, and the latent heat released heats up the water passing through the condenser tubes; the heated seawater passing overboard into the sea, to be replaced continuously by fresh cool water. The resulting condensate will be somewhat warmer than the seawater coolant.

EVAPORATION: This is the process of converting a liquid into a vapour, and it requires latent heat to do this. If a liquid (say liquid propane) in a closed container at 10 deg C. has a saturated vapour pressure of 5 atmospheres, and the vapour in the space above the liquid is allowed to escape, the pressure in the container will fall. As soon as this happens, the vapour in the space above the liquid will be undersaturated and evaporation will take place (or the-liquid boil). Heat will be used up in the boiling process and the temperature of the liquid will fall. The "boil off " will largely replace the vapour which has been allowed to escape until such time as the pressure in the container corresponds to the saturated vapour pressure of the liquid at the new lower temperature. Continuous withdrawal of vapour means continuous evaporation, which in turn means continuous loss of heat (cooling down).

FILLING OF CARGO TANKS: The correct maximum volume of liquid to load in a cargo tank is such a quantity that after allowance for the product to warm up and expand to a temperature the saturated vapour pressure of which would lift the safety valves, 2 per cent. of the space would remain. A tank so filled is described as *Full*. A tank filled above this level is described as *Overfull*. A tank completely filled with liquid is described as *one hundred per cent.*

GAS/VAPOUR: Gas is a substance which has the property of indefinite expansion. In the context of this book, it is above its critical temperature and cannot be condensed into a liquid. If the temperature of a gas is reduced to below its critical temperature, it then becomes a vapour, and can be condensed into a liquid. Gases are frequently referred to as incondensibles.

Flammable or Explosive Mixture.- Petroleum as a liquid does not burn. At ordinary temperatures, it gives off vapour, which when mixed within certain proportions with air, will burn. The lowest proportion of petroleum vapour in air mixture which will burn is termed lower explosive limit (L.E.L.) and the strongest mixture that will burn is termed upper explosive limit (U.E.L.). The flammable mixtures between the lower and upper explosive limits is called the explosive range. A mixture of vapour in air weaker than the L.E.L. is described as too lean or over-lean whilst a mixture of vapour in r stronger than the U.E.L. is described as too rich or over-rich. Mixtures outside the explosive range will not burn, the words explosive and flammable within this context being virtually synonymous.

Flash Point.- This is the lowest temperature at which a flammable mixture of air and vapour will burn when exposed to a naked flame.

Ignition Temperature.- This is the temperature at which a flammable mixture of vapour and air will ignite spontaneously (without being exposed to a naked flame). The operation of a diesel engine depends upon this effect.

GAS LAWS

Avogadro's Hypothesis. Equal volumes of different gases at the same pressure and temperature contain the same number of molecules.

Boyle's Law. The volume of a given mass of gas varies inversely with the pressure provided that the temperature remains constant:

$$P = \frac{1}{V}$$

Charles's Law. The volume of a given mass of gas varies directly with the absolute temperature provided the pressure remains constant:

$$volume = \frac{273 + t}{273} \quad \text{or} \quad density = \frac{273}{273 + t}$$

Clerk Maxwell's Kinetic Theory: A gas may be imagined as a vast number of molecules moving in all directions at irregular velocities, colliding with one another and with the walls of the containing vessel. The path of a molecule is zigzag in three dimensions and the mean free path is defined as the average length between collisions, the denser the gas, the shorter will be the mean free path.

On the assumption that the molecules are microscopic spheres, it can be shown that the pressure and absolute temperature of a gas are proportional to the mean kinetic energy of translation of the molecules bombarding the walls of the vessel containing the gas. Thus, at the same temperature the average kinetic energy of translation of the molecules of any gas is the same whatever its mass- a "large" molecule having low velocity and a "light" molecule having high velocity.

This theory correlates Avogadro's Hypothesis, Boyle's Law, Charles's Law and Gay Lussac's Law.

Dalton's Law of Partial Pressures: The pressure of a mixture of gases is the sum of the pressures each would exert if it alone were to occupy the containing vessel.

Gay Lussac's Law: The density of a gas at standard pressure and temperature is proportional to its molecular weight. This is a corollary of Avogadro's Hypothesis.

Joule's Law: When a perfect gas expands without doing external work and without taking in or giving out heat and therefore without changing its stock of internal energy, its temperature does not change.

HEAT

Latent Heat: This is the heat used up in changing the state of a substance without changing its temperature. In the, case of changing the state of a substance from a solid into a liquid (melting), it is called the latent heat of fusion, and in the case of heat changing the state of a liquid into a gas or vapour (boiling), it is called the latent heat of vaporisation. It takes 80 calories to change 1 gramme of ice into Water and about 539 calories to change 1 gramme of water into steam at standard atmospheric pressure. The value of latent heat of vaporisation varies with temperature and pressure (see critical temperature).

Sensible Heat: This is the heat used in raising the temperature of a substance without changing its state. 1 calorie is used to raise the temperature of 1 gramme of water 1 deg C.

HEEL: This is the small quantity of liquid remaining after discharge which it is impossible to pump out, but which is used to assist in keeping the cargo tank cold during the ballast (unloaded) passage, and is usually carried over to the next loading. When it is known that the vessel will be changing grades or gas-freeing, every effort should be made to reduce this heel to the absolute minimum.

LIQUID CARRY OVER: This occurs when vapour moves swiftly over the surface of a liquid and droplets of liquid become entrained with the vapour and are carried over with it.

It is the entrained droplets of lubricating oil which are recovered in the lubricating oil separator trap of the compressors, and entrained liquid droplets which cause wet suction on a compressor.

MOLE: This is the quantity of gas the weight of which is equal to its molecular weight in pounds or grammes. Thus a mole of hydrogen would be 2, a mole of oxygen 32 etc. This is fairly closely related to Avogadro's Hypothesis, a mole having the same volume for all products at the same pressure and temperature.

PRESSURE

Absolute Pressure: This is the pressure above a vacuum. Thus a pressure of 7 p.s.i. absolute, is really a suction pressure of 7.7 p.s.i. at atmospheric pressure (atmospheric pressure equals 14.7 p.s.i.).

Gauge Pressure: This is the pressure above one atmosphere and is the usual method of measuring pressures and vacuums. Absolute pressure is therefore equal to gauge pressure plus one atmosphere.

Atmospheric pressure: This is the pressure exerted at sea level. This pressure varies from place to place and from time to time. The standard atmospheric pressure is 1012.5 millibars, corresponding to 29.90 inches or 760 millimetres of mercury.

SPAN GAS: This is a laboratory-measured mixture of gases used for the purpose of calibrating gas detectors. In gas tankers, the mixture is usually 30 per cent. L.E.L. of the product mixed with pure nitrogen.

STRATIFICATION: This is the layering effect of two gases or vapours with dissimilar densities, the lighter vapour floating above the heavier.

TEMPERATURE

Absolute Temperature: As a result of studying Charles's Law, it seemed that the volume of a gas would reduce to nothing at about –273 deg C. (or absolute zero). (Physicists have never been able to reach this temperature.) it therefore follows that absolute temperature equals temperature + 273 deg C.

Adiabatic Changes in Temperature: When a gas (or vapour) is compressed, its temperature rises. When it expands, its temperature falls. This is the adiabatic process and compression ignition (diesel) engines rely upon this property for their operation.

Critical Temperature: This is the temperature above which it is not possible to liquify a gas. Saturated vapour pressure rises with an increase in temperature. At the same time, the density of a liquid falls with an increase in its temperature. Therefore, there must come a time when so many atmospheres of pressure are required to liquify the vapour that the density of the compressed vapour and the liquid are the same. When this state is achieved, there is virtually no difference between the liquid and vapour phases and they freely change into each other. The value of latent heat is reduced to zero and with any increase in temperature, no amount of increasing the pressure will bring about liquefaction, and I the vapour is then described as a gas. Associated with the critical temperature is the critical pressure.

VAPORISATION: This is the action of converting a liquid into a vapour.

Batch Vaporisation: This is the method of evaporation whereby vapour is withdrawn from the top of a tank, causing the liquid in the tank to boil, with a consequent drop in temperature. Also, with a mixture of products such as butane and propane, the more volatile element tends to evaporate first, so that the proportions comprising the mixture will change and after a time one is left with almost pure butane. This process of altering a mixture in a tank due to the volatile constituent evaporating first is called *"weathering"*. However, batch vaporisation is the simplest method and because, in L.P.G. tankers, the vapour which has been withdrawn is condensed into a liquid and returned to the tank, there is no tendency to alter the constituents of the mixture, so this is used as a method of refrigeration.

Flash Vaporisation: This is the method whereby liquid is withdrawn from the bottom of the tank and evaporated in a vaporising unit. In this method, the constituents of a mixture remain fairly constant, as does the temperature of the product in the tank.

VAPOUR: This is the term used for a "gas" below its critical temperature and therefore capable of being liquified.

Saturated Vapour Pressure (S.V.P.): All liquids tend to evaporate under normal conditions, but if kept in a closed container, evaporation will only take place until the atmosphere in the container becomes saturated. In the case of water, the following experiment can be carried out. Into the top of a barometer some water is introduced. Due to the evaporation of the water that has been introduced, the level of the mercury will fall. If sufficient water is introduced, the level will virtually stop falling because the space above the mercury will be saturated with water vapour, and a little water will show on top of the mercury. The fall in the mercury level converted into pressure would indicate the absolute S.V.P. at that temperature. By raising the temperature, more water will evaporate and the level of the mercury fall further. The new level, converted into pressure, will indicate the new S.V.P. at the new temperature. At 100 deg C., the level of the barometer will register zero. The absolute vapour pressure of water at 100 deg C is therefore one atmosphere (1.0125 bar). It therefore follows that under atmospheric conditions, a liquid will, apart from minor evaporation, keep its state until with the addition of heat, its absolute S.V.P. reaches one atmosphere. From then on, all the extra heat will be used to assist evaporation and the temperature will not rise. In other words, the liquid boils. If the boiling action takes place in a closed container, e.g. a boiler, as the temperature rises, so the pressure increases. That is, the boiling temperature of the water rises as the pressure increases. The pressure in the boiler is an indication of the water temperature and vice versa.

If a thermometer and pressure gauge were fitted to a container holding, say, propane, the temperature and pressure would be directly related to each other, the pressure rising as the temperature rose and vice versa.

A sudden release of pressure would result in continuous evaporation, this using up latent heat so cooling the liquid until the temperature of the liquid reached that appropriate to the S.V.P. of the product at the new pressure.

This means that if warm propane escaped onto the deck, it would immediately evaporate and refrigerate itself down to approximately - 43 deg C.

Supersaturated Vapour: If the vapour pressure in a container is rapidly increased, condensation will take place, but until the process of condensation has been completed, the vapour will be supersaturated.

Undersaturated Vapour: This is super saturation in reverse.

Superheated Vapour: In the absence of liquid to continue the evaporating process and so keep the vapour saturated, the vapour temperature can be raised to well above the temperature corresponding to that at which the vapour would be saturated at the pressure concerned. Any superheated vapour would have no tendency to condense. This property is used particularly with steam. The saturated steam coming from the boilers is heated further in the superheater to prevent condensation taking place in the engine.

VAPOUR RETURN LINE: This is a balancing pipeline between the ship when loading (or discharging) and the shore tank, so that the vapour trapped in the space above the incoming liquid, and therefore being compressed, is returned to the shore tank from which the product is being discharged.

ZERO GAS: This is pure nitrogen used to calibrate the zero reading of gas detectors.